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What matters? Unlocking householders' flexibility towards cooling automation in India

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ABSTRACT

In emerging economies like India, where air conditioners are projected to triple by 2050 — mostly from household use — demand response programs such as cooling automation have gained currency as a suitable approach to address peak electricity from cooling demand. Environmentally commoning/intentional communities are classic contexts in which flexible cooling consumption might be easily realised. Utilising materialist theory and a six-month cooling automation trial, surveys and workshops with twenty households in an intentional community in South India, this study explores factors that shape householders' pliability or rejection of cooling automation. Results reveal that while commoning identity plays a significant role in householders' flexibility towards automation, extreme heat creates a clash between householders' environmental beliefs and comfort needs, altering their response to automation. We conclude by discussing the theoretical implications arising from these findings and suggest how utilities could respond to these dynamics to foster a transition to a low-carbon energy system.

1. Introduction

In the Global South, electricity systems are experiencing transformations due to the growing penetration of renewables and the rise in electricity demand. In India, the demand for residential air conditioners (ACs) fuelled by increased severity and frequency of heatwaves, population and income growth have become a major component of increasing electricity demand (IEA, 2018; Osunmuyiwa et al., 2021). India's projected cooling-related electricity demand is expected to double by 2030, and it has been estimated that India would need to invest USD 304 billion in its electricity grid to meet these demands (IEA, 2018).

Amongst policy, industry and research experts in India, there is a consensus that automation of residential AC systems to permit demand response (DR) could be a favourable policy response to emerging cooling-related electricity needs because of its potential to minimise cost, assist with grid integration of renewable energy sources, reduce network load volatility and improve grid reliability (Osunmuyiwa et al., 2021). Most ACs have flexibility potential, permitting load response within seconds and response duration of minutes with minimal discomfort for occupants. In addition, cooling demand is coincident with peak electricity loads during the summer making residential ACs good candidates for demand response (for further insights see (Yi and Peng, 2019; Yin et al., 2010). However, the acceptability of cooling automation will be a function of user perceptions of how their thermal comfort is modified in pursuit of the required flexibility. This is likely to place a constraint on the scale of flexibility provided particularly as automation

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technologies are designed to permit users to manipulate and override systems to satisfy users' cooling needs (Strengers et al., 2021). User preferences around automated cooling adjustments are likely to be influenced by the magnitude and frequency of the changes requested together with other varying concerns around loss of control, agency, equity, data privacy and a low level of trust in the utility (Carmichael et al., 2021). Automation further raises issues regarding the negotiations and framings around DR in the electricity sector and as such there have been calls (Adams et al., 2021; Osunmuyiwa et al., 2021) to critically unpack who benefits or becomes excluded from these narratives.

Given the identified constraints around householder acceptability of cooling automation, the significant impacts of increased cooling demand on India's grid and the financial implications of rolling out a DR program that could be rejected, we propose that ecologically conscious intentional communities or environmental commoning sites could serve as test grounds for cooling automation. We follow the work of feminist scholars (Federici, 2008; Nightingale, 2019) and define environmental commoning and intentional communities as communities built on values of sustainability, socio-economic solidarity, and de-growth that resist neoliberal property-centric conservation practices. Commoning within these sites involves a departure from the notion that 'nature's bounty is to be squandered' and moves towards a reimagination of human interactions with nonhumans as an active intertwined process embedded in practices, labour, experiences, and negotiations around sustainability and sharing within a community (Adams, 2015; Linebaugh, 2008).

Ecologically driven intentional communities or environmental commoning sites offer a critical empirical and analytical lens for exploring possibilities about how new technologies such as cooling automation may embed and enact new configurations and sites of socio-ecological relations and practices. Empirically, these sites have [re]gained traction amongst a diverse coalition of actors as experimental laboratories for participatory forms of energy utility and post-capitalist forms of collective energy production and ownership (Moroni et al., 2019; Sherry, 2019). By their experimental nature, intentional communities can provide valuable insights into the negotiations and contestations that could enable/hinder the acceptance of cooling automation at the household level (Chatterton, 2016; Hausknost et al., 2018; Rubin, 2019).

Analytically, focusing on ecologically driven intentional communities allows us to engage with the materialist and commoning literature in science and technology studies (STS) and contribute to the growing theorisation in the sustainability transitions, social-practice domain and social studies of market literature on how sociotechnical systems like electricity infrastructures and data-driven smart technologies assemble and transform societies while simultaneously governing interpretations of social action and change (Adams et al., 2021; Fjellså et al., 2021; Sadowski and Levenda, 2020; Strengers et al., 2021). Current contributions on household use of automation remain largely exclusive to advanced economies and are typically centred around appliances like dishwashers and washing machines (Parag and Butbul, 2018; Pratt and Erickson, 2020) that might likely not provoke insights on how alternative socio-nature[1] relations that protest current hyper-consumption might emerge. Luckily, social science perspective on domestic heating biographies (Butler et al., 2016; Eon et al., 2018; Shirani et al., 2017) or cooling automation in office buildings (Aghniaey and Lawrence, 2018; Hu et al., 2017) have begun to emerge. Still, more analysis is needed to understand how emerging climatic changes will impact domestic energy relations and recalibrate social, technical, and institutional discourses around 'sensible' ways of living.

The materialist/commoning literature provides two analytical merits as DR /flexibility policies become visible in everyday conversations about energy transitions. First, it moves our understanding of energy flexibility and cooling automation beyond current discourses of resource security for utilities and savings for households that have successfully crowded out ecological visions for socio-technical 'smartness' (Sadowski and Levenda, 2020). Rather, with ACs increasingly being considered 'indispensable' (Strengers et al., 2021), it forces us to interrogate together how automation and emerging climate threats (heatwaves) will place new levels of flexibility demands (i.e. acting in ways that break with habits) on householders than they are previously used to and create new socio-nature relations (changes in human/environmental relations) within the domestic. Understanding the dynamics in which these socio-nature relations will unfold is important for sustainability transitions because it is not just society's relationship with energy and by extension cooling that is in question, but the social nature of cooling itself may produce questions of power and environmental trade-offs in the operation of socio-technical systems like automation (see Smith and Stirling, 2008).

Second, as automation flexibility will not only transform the role of households in energy transition pathways but lead to a reimagining of the domestic, engaging the materialist dimension helps us to unpack who and what counts for flexibility of socio-technical grids within different domestic spaces. This is important because socio-technical systems like automation are neither value nor scientifically neutral and cannot be understood outside their socio-cultural, politico-economic, and ecological contexts (Nightingale et al., 2020; Sadowski and Levenda, 2020). Thus, using the deployment of a residential AC DR pilot trial (called DAC) in our case community (Auroville, India) and drawing on qualitative data (workshops and surveys) from 20 participating households, we analyse how automation clashes with relational meanings attached to cooling within the domestic; unpack subjectivities (i.e., cultural codes, rules, group practices and power relations) and complexities of eco-social relation that shapes who and how flexibility is provided. This helps us to evaluate the processes that mediate responses to socio-environmental stressors (Nightingale et al., 2020); unpack how membership in intentional communities' (typically touted as test beds for these types of innovation) may moderate how householders interact with cooling automation, how this enhances or undermines the goal of energy transitions via flexibility and the lessons these may provide for automation designers.

[1] Socio-nature is a concept from critical ecology that sees "constitutive intimate relations with human and non-human components of the environment as one and the same". Studies on socio-nature relations seek to dislodge the commodification, marketisation and externalisation of nature (see, (Harvey, 1996; Swyngedouw, 2004). It is distinctive from 'socio-ecological systems (SES)' because in SES, ecologies and societies are treated as separate, and whereas with socio-natures the focus is on understanding relations that affect societies and ecologies (Nightingale, 2019)

2. Conceptual framework – flexibility in sustainability transitions

The use of digitalised and technologically advanced systems such as building control systems and automated smart appliances to achieve flexible load shifting or dynamically curtail use during high demand has become one of the key techniques to encourage users to participate in DR, shift demand, ensure grid reliability and promote sustainability transitions (Fjellså et al., 2021; Kobus et al., 2015; Wiekens et al., 2014). Automation targets flexible watts i.e., consumption that can be shifted across different parts of the day within boundaries of acceptable "compromise" to comfort, this being within the auspice of the user to define. From this point of view, automation 'tames' the complexities attached to the provision of flexibility by utilising information communications technologies to reduce users' involvement to the barest minimum (Parag and Butbul, 2018). For DR advocates, the ascribed "taming" capacity of automation allows for continuous interaction with the grid and de-centres the householder from actively engaging in this process (Parag and Butbul, 2018).

While we agree that automation to an extent reduces householders' need to interact with the DR process, however, we believe that taking automation as a starting point of analysis means we fall into techno-optimist narratives that tend to privilege the technologically possible above the realities of markets or the people who co-opt such technologies (Strengers et al., 2021). Furthermore, we lose sight of the socio-relational aspects of the technologies (ACs) that enable how or whether automation is accepted by the user or not. Our standpoint aligns with recent critiques from sustainability transitions, market studies, practice theorist and feminist scholars who have all argued that efforts to reposition the user via 'Flexi framing' not only simplifies the complexities that accompany electricity flows in domestic practices of everyday life but positions householders as 'calculative actors' that are equipped to absorb and support these new technological configurations (Christensen et al., 2020; Skjølsvold and Lindkvist, 2015; Strengers, 2014). Social science sustainability scholars remain sceptical of the ascribed role of users as envisioned by DR advocates. Instead, some authors (Christensen et al., 2020; Pallesen and Jenle, 2018) advocate for pragmatic prepping of users in a way that allows them to perform calculative agencies (price-driven electricity use) in their practices, others have explored the use of market approaches like customer journeys and trust to create emotional connections between user and products (de Wilde, 2020). While these approaches have led to insights on the utility of market calculations and trust relationships that lead to organizing frameworks for accepting engineering solutions like automation — yet, as these approaches show, the ability to respond to economic nudges or become emotionally attached depends on the material devices in question and relational subjections of users (i.e., ways of understanding).

Beyond the marketized and instrumentalised view in the transitions literature, material and relational subjectivities can help us interrogate how 'things other than humans (nature) make a difference in the way technologies and social relations evolve' (Bakker and Bridge, 2006). To explore this material and subjective dimension, we draw insights from critical science and technology studies (STS) and commoning literature which emphasises the often-overlooked, material and subjective work necessary to reconstruct everyday interactions with humans and the natural world. This literature provides socio-nature (ecological) dimensions of human experiences that current transition studies miss out on and is a departure from the techno or environmental deterministic approaches that obscure the relational interactions between socio-economic, political, and ecological processes that influence transition outcomes. Taking inspiration from Worster (1985), it helps envision transitions "where neither nature, humans nor technologies like cooling automation ever achieve sovereign authority but continue to make and remake each other."

2.1. *Cooling automation as materially constituent and subjectively relational objects*

A sub-field of science and technology studies (STS), the materialist literature de-centre humans as the primary or sole subjects of analysis, but rather focuses on the different ways in which human subjects and non-living objects inter-relate and affect each other. Fuelled by a broader interest in the interactions between humans and environmental systems, the materialist literature not only unpacks how non-human objects for instance shape energy consumption in the domestic (see (Strengers et al., 2016), but also redirects us to account for how the co-presence of 'natures' (climatic changes own emphasis) and inanimate objects (in our case ACs) intertwine in shaping the everyday life, identities, and the politics of value within domestic spaces (Bakker and Bridge, 2006; Nightingale, 2019).

Particularly, we situate ourselves in critical materialist literature and apply this view as it allows us to think about flexibility as a transition approach in three new ways. First, its positionality on technological objects like automation as "apparatuses"[2] by which life or in this case cooling is 'administered' or 'managed' provides insights into how the administration of life (or what Foucault calls biopolitics) is shifting because of how new technologies, practices, and knowledges that either did not exist or previously appropriated are being co-opted to manage socio-nature relations. Apparatuses like automation not only seek to manage everyday activities like cooling but by providing householders with environmental or price savings, it introduces feedback that becomes internalised and considered in decision making. This not only regulates how ACs are used but transforms cooling into a site of administration and government (Braun, 2014).

Yet, to understand the administrative role of technical objects like automation, one must go back to the initial device that facilitates such administration i.e., ACs and how by design it is inscribed with "specific tastes, competencies, aspirations,"(Akrich, 1992) that produces certain kinds of subjects and socialisations (Sadowski and Levenda, 2020). This brings us to our second point which is that the materiality literature provides insights on the subjectivities that informs AC use (broadly described as 'ways of understanding, perceiving, and relating to the world or the home'). It shows how ACs as technical apparatuses' engage with humans through

[2] Giorgio Agamben (2009, page 14) defines 'apparatus' as "literally anything that has in some way the capacity to capture, orient, determine, intercept, control, or secure behaviours, opinions, or discourses of living beings".

'practices' of use, need, exchange and disposal to constitute a huge part of human social relations (Read, 2011; Singh, 2017). Through apparatuses like ACs, (Agamben, 2009: 14–17) argues, man seeks to "enjoy being" and "at the root of each apparatus lies a human desire for happiness". Based on the desire for happiness—the subject is available to be 'managed'.

Thirdly, and most importantly for our site of enquiry, the critical materialist lens provides answers to questions long posed by sustainability transitions scholars or more concretely as Guattari (1995:119–20) asks 'how do we reinvent social practices that would give back to humanity — a sense of responsibility, not only for its survival but equally for the future of all life on the planet?' by pointing to commoning sites as places where alternative structures of relations between apparatuses, humans and nature can be realised (Singh, 2017). In commoning sites, everyday interactions between the social (through apparatuses like automation and ACs) and the natural world is reconstructed through rules, codes and conducts that reorganise production and exchanges between humans and non-humans in a way that is resistive to the dominant capitalist orientation of hyper-consumption (Nightingale 2019). In the next section, we explore how this reconstruction occur.

2.2. Conceptualising the materiality and subjectivity of cooling in ecologically driven intentional communities

Ecologically driven intentional communities, as one of many forms of spatially delimited commoning sites, pursue a distinct goal of practising sustainable lifestyles (Hardt and Negri, 2009). Intentional communities are mutually constituted and materially connected through shared spaces and resources and commoning in these spaces involves a reconfiguration and reorganisation of human and non-human relations (Nightingale, 2019). One of the areas in which this reorganisation unfold is the use of energy resources. This is obvious in their deliberate attempts at becoming the "socio-technical laboratories for the future" where low-carbon technologies and energy efficiency measures are adopted to decomodify nature and engender a transition to alternative socio-technical and economic systems (Ruiz Cayuela, 2021). The materiality and management of energy manifest in multiple ways but we focus on two for their importance for cooling.

I The concern for material energy autonomy. This unfolds in the self-generation of energy (typically from renewables) aimed at diminishing dependence on an external and oftentimes 'dirty' energy supply (Rubin, 2019).
II How the physical structures of the homes are designed to embody the goal and values of low-carbon energy use. As seen from the literature, building structures and practices in intentional sites not only serve as 'architectures of intimacy' they are also symbolic in shaping the forms and function of commoning and signalling the ecological principles of such communities (Escribano et al., 2020).

Beyond their materiality, energy use in intentional communities is also subjectively relational. This is because energy use is synchronous with webs of daily practices and routines through which people reproduce socioecological sustenance within the commons (Esteves, 2017; Federici, 2008; Hall et al., 2018). The process of reproducing socioecological sustenance becomes a site for socio-nature relations as it serves as means of melding together diverse ways of thinking, using, governing and rulemaking about the use of energy in commons while simultaneously nurturing subjectivities of 'being in common' with others (Nightingale, 2019; Singh, 2017). Subjectivities around energy use manifest in multiple ways but we focus on two for their importance for cooling.

I Shared imaginaries[3] to reproduce socioecological sustenance within the commons through the articulation of environmental ethics around energy consumption. These imaginaries are embodied as 'techno-biospheric ethics'" articulated through the deployment of eco-objects or in this case energy-efficient appliances to influence energy consumption (Hobson, 2006).
II Shared imaginaries around energy use within the commons vis-a-vis rulemaking and governance structures around energy consumption (Nightingale, 2019). This can play out either in rules about the types of technologies allowed in the common (no ACs for instance or only energy efficient ACs) or the commoning of technological objects such as the use of communal laundry machines and communal kitchen spaces and appliances to reduce the community's environmental footprint.

2.2.1. Cooling automation moderators in intentional communities

While energy use might be materially 'commoned', yet, our object of analysis, cooling — remains a rather subjectively individualistic affair in intentional communities. This is because ACs remain mostly used in individual houses based on individual needs. As demonstrated in Sections 2.1 and 2.2 ACs are objects involved in the production of subjectivities which hold the potential to challenge the perception, distribution and normalisation of what is (or should be) commoned and excluded (Nightingale, 2019). As such we argue that three important factors might shape how cooling automation unfolds and the degree of cooling flexibility achievable within intentional communities. These factors are explored below.

I Shared imaginaries around the socio-ecological sustenance and biospheric use of energy can enable the provision of cooling flexibility. There are several reasons why subjectivities around shared imaginaries on the socio-ecological use of energy might

[3] Our understanding of shared imaginaries is situated in the STS and ecology literature (see Jasanoff,Adams et al 2015) that conceptualises sociotechnical and ecological "imaginaries" as collectively held, ideologically driven, institutionally stabilised and openly performed visions of living that are based on shared normative understandings and relational conceptualisations around social life and order.

enhance the adoption of cooling automation. These include the maintenance of environmental identities and biospheric ethics individuals subscribe to as being a commoner, the collective biospheric goals of reducing the community's environmental impacts and ensuring energy autonomy and members' willingness to maintain and alter the physical and spatial configurations of their homes to fit emerging environmental needs (Tummers and MacGregor, 2019). While these collective identities and biospheric values might drive individual decisions to engage in pro-environmental behaviours (i.e. acceptance of cooling automation technologies) (Van der Werff et al., 2013). As seen from recent research, caution must be exercised, as a collectivist orientation within intentional communities around 'biospheric values' can become unstable once it collides with individuals' perceived cooling consumption needs especially when this plays a vital role in the constitution of social processes at home (Osunmuyiwa et al., 2020).

II Increased climate severity as a moderating factor in the provision of cooling flexibility. We argue that despite commoning materialities around creating buildings that passively regulate coolth in intentional communities, experiential changes in the physical and visceral workings of the body based on emerging heatwaves will have an impact on householders' sense of agency and willingness to provide automated cooling flexibility. We further highlight that as the climate becomes more severe, the materiality of the home and its role as a form of connective tissue that links experiential events of the human psyche and corporeal not only becomes visible but might shape how individuals within intentional communities respond to and/or attribute emotional agency to heatwaves (Davidson and Milligan, 2004). As existing research shows, bodily sensory engagement with heat is modulated by environmental conditions, metabolism, age, gender, sensations, or tolerance (Lam et al., 2018; Sherriff et al., 2019) and when affected by new temperate extremes there is a tendency to 'provoke' emotional responses such as rebellion against systems of control like cooling automation put in place to govern comfort (Lopes, 2010; Sarran et al., 2021).

III Rulemaking and governance structures within the community can enhance or debar householders' acceptability of cooling automation. The integration of cooling automation will be contingent on continuous negotiations and re-negotiations around who and what type of appliances belong to 'the community' through rules that not only create and regulate socio-nature relations but are crucial to holding the community together (Nightingale, 2019). We argue that defining new rules to automate cooling in an intentional community can rarely be achieved without significant negotiation with the community's utility, homeowners, and community leadership. This will also involve discussions on techno-behavioural changes necessary to replace existing cooling practices. Yet, while negotiations around cooling automation, in this case, can be positive, they can also contain some ambivalence and contradiction around the exercise of power that might not necessarily foster nurturing relations with the proposed technical changes (Nightingale, 2019). An example would be community members seeing the value in providing cooling flexibility but changing their minds when trust and data privacy issues crop up or seeing the introduction of such technologies as interfering with other existing technologies at home (e.g., sockets). As shown by commoning research, such ambivalence is not unusual because commoning practices emerge from and create emotional subjections to the community, resources/non-humans (Singh, 2017) but when contradiction emerge, this can lead to distrust and might not foster nurturing relations that support the proposed technical transformations.

In the next section, we look at our case study site and apply the materialist perspective as an analytical lens to understand factors which influenced the acceptance of cooling automation and the degree of flexibility realised.

3. Case context: auroville

The analysis begins with a universal and intentional community in India known as Auroville, situated at latitude 12.0052 and longitude 79.8069 in Tamil Nadu, Southern India. It has a sub-tropical climate and has been in existence for over 50 years. Auroville is home to 2677 residents composed of different nationalities. It is a semi-autonomous community that strives for self-sufficiency in energy, food and other aspects of resources required by the community (Auroville Consulting, 2018). All residents of Auroville earn the same amount of money — a monthly stipend for their work in the community. Right from its inception, the community has been involved in sustainability research across various fields including agriculture, energy, and architecture. Energy conservation and sustainable use of energy is a core pillar within the community. The quest for material energy autonomy is visible in the community with over 500 houses using some form of solar energy, the presence of 230 kW grid-connected solar capacity to reduce grid imports and the improvement of its net carbon position through ownership of a remote 4.8 MW wind farm. The community also has its local utility, known as Auroville Electrical Services (AES) and since 2011, the community has enacted a free electricity support program for all residents. AES meters and gives residents bills showing their monthly consumption. It also serves to notify householders of excess consumption (Osunmuyiwa et al., 2021).

Another area where the materiality of the community is made visible is in its historical philosophy antecedent of buildings being designed and built to optimise passive ventilation and manage daylight to embody the values of low-carbon energy use. Subjectivities

Table 1
AC ownership by sector and in total.

	C&I	Domestic	Public services	Total
ACs identified (nos.)	62	170	68	300
Service connections (nos.)	450	1500	200	2150
AC ownership rate (%)	14%	11%	34%	14%

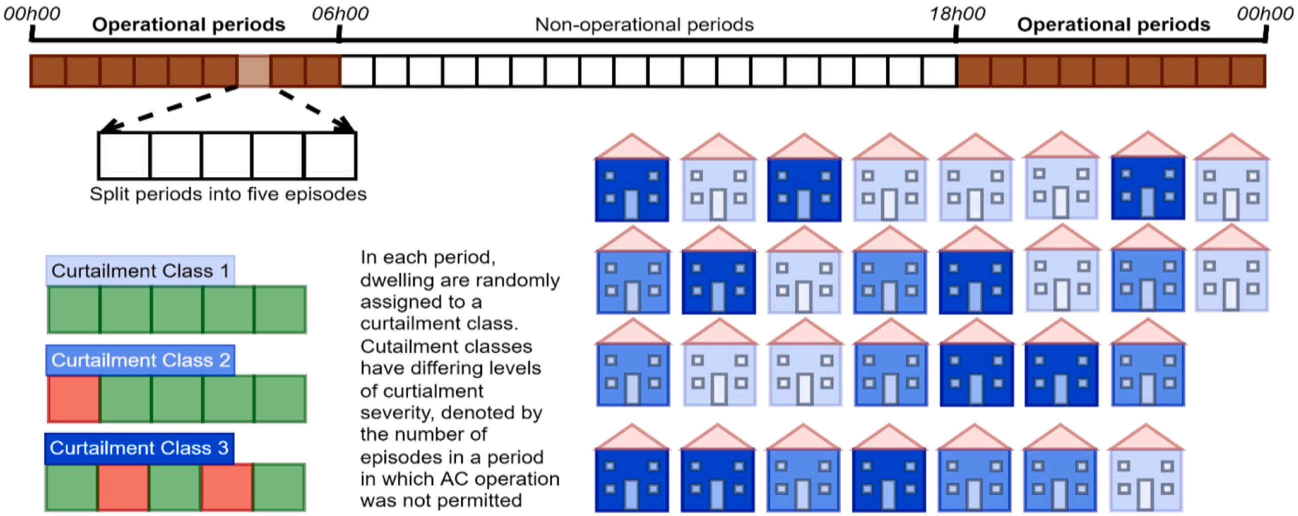

Fig. 1. DAC methodology Schematic.

around energy consumption vis-a-vis rulemaking around AC use are also very strong in Auroville. ACs were prohibited for three decades within the community. However, in the last decade rules around the use of ACs have been relaxed, in response to both increased severity and a broadening of the summer climate particularly since 2013 (Debnath et al., 2020). An extensive survey and mapping exercise was conducted to understand the current domestic AC ownership rate and the geographical location of installed air-conditioners. The overall household AC ownership rate in Auroville was found to be 11 per cent (Table 1), with the increase in ownership alluded to earlier likely to be a causal factor in per-capita annual electricity consumption rising from 1610 kWh in 2010 to 2500 kWh in 2020: circa twice the Indian average (Osunmuyiwa et al., 2020).

4. Methodology

4.1. AC system control approach & details of a pilot trial

The classical definition of DR is a deliberate intervention by the utility in the marketplace to change the configuration or magnitude of the load shape. The emergence of home-area networks and smart metering has created new possibilities for two-way DR programmes to be developed for small loads such as residential AC systems. These can enact different models that seek to provide multi-objective control allowing AC system efficiency to be optimised within a framework of grid management provision negotiated with an aggregator or the utility. Issues do abound with this level of sophistication; interruptions in data access can disrupt control systems that rely on real-time applications. To overcome these limitations, the control philosophy adopted sought to access load flexibility from aggregated residential ACs whilst minimising system data requirements. The rationalisation of demand response at the individual dwellings was not pursued; rather the aggregated load signature from participating dwellings was interrogated to elicit the impact of aggregated control.

The impact of revised control on the internal temperature in a selection of dwellings was evaluated to permit a discussion about grid management versus thermal comfort provision. Two project partners, Auroville Consulting (AVC-local) and Findhorn Innovation Research and Education (FIRE-partially local) helped with the recruitment of the participating dwellings through word of mouth and advertising in local media outlets and on social media. Thirty dwellings were identified as being suitable for participating in the programme. As with most DR-related experiments, the selection suffered from “participation selection bias” in that those who participated were familiar with the project, households had prior interactions with a sister project conducted by the authors which had discussed the potential of a trial cooling automation within the community and already had ACs. AVC was responsible for the deployment of the sensors. Each household lived separately across the community with each participating dwelling fitted with (i) a smart plug to allow AC operation to be interrupted and (ii) a sensor to measure internal temperature and humidity. AVC support teams managed installation, provided information about the trial scope and dealt with household enquiries.

The DAC methodology splits each day into 40-minute periods (Fig. 1). Each 40 min was then split into eight-minute episodes. Eight minutes was selected as the episode duration as it permitted the AC system to close down safely during episodes where the power was cut. At the start of each 40 min, each participating dwelling was randomly allocated into one of three groups.

- Group 1- AC is allowed to operate in all five eight-minute episodes within the 40 min
- Group 2- AC can operate in only four out of five episodes. In the remaining episode, power was cut to the AC system. The off episode is randomly allocated within the five episodes in each period.
- Group 3- AC can only operate in three out of five episodes. In the remaining two episodes, power was cut to the AC system. The off episodes are randomly allocated within the five episodes in each period.

Participating dwellings could not be assigned to Group 3 for two periods in a row. The distribution network to which the participating dwellings were connected had a high penetration of connected PV systems. Voltage instability occurred at certain periods of the day when PV generation dominated power flows in the distribution network. During these voltage excursions, AC systems installed with an inverter did not operate. Consequently, DAC control only operated from 6 pm until 6 am to ensure that any AC system interruptions could be traced to project control. The trial operated during the first wave of the covid-19 pandemic from March and September 2020. Initially from March 3rd to May 18th, no control was enacted to allow data to be collected to define baseline conditions and construct usage personas with respect to thermal comfort and AC usage. From May 19th onwards, DAC control was enacted, with different configurations being tested to explore rebound effects and also the impact of increasing curtailment. Only the standard control period, as described above is reported in the following results, with control impact evaluated over 10 days from May 19th to May 29th.

4.2. Workshop- and Survey feedback

The workshop took place in June 2021 during the second wave of covid-19 in India. Due to covid-19 lockdown restrictions, we could not meet householders individually. As such, a socially distanced workshop became the preferred mode of communicating with trial participants. The workshop was conducted in a hybrid manner over zoom and in person. Some members of the research team were in the UK while the rest of the team was in Auroville. The DAC team recruited households that were in the control exercise to participate in a workshop and surveys with 20 out of the 30 households from the trial participated in the workshop. Workshop participants could be discretised by household composition: (i) five females lived alone, (ii) seven males lived in shared households, yet made energy purchasing decisions alone and (iii) eight couples made decisions collaboratively. Household participation in the workshop exercise was an opportunity to provide in-depth insights into the factors shaping households' willingness to participate in cooling flexibility. During the workshop, the impact of objective and subjective factors, internal and external to householders (e.g. age, commoning, sex and increasing temperature) on householders' ability to provide automated cooling flexibility were assessed.

The workshop was divided into three phases. In the first phase, the project partner (FIRE) presented our extracted 30-year weather data for South India and statistics on the growth in installed domestic ACs in the 10 years were presented to participants. This data was presented to spur discussions around climate change, the growth in ACs and its impact on electrical demand. In the second phase, the second author presented the DAC project, the objectives behind deploying cooling automation within the community, the types of data collected and the results from the field trial. We concluded this session by placing participants in break-out rooms and asked to discuss how they coped with the control systems and what practices had to be adjusted; when it was non-negotiable to switch off their ACs and why. We probed further by asking about the activities carried out during this period, whether these activities were related to or shared with other people within the home and how this might affect their ability to provide flexibility. The third phase was an open discussion with participants about the potential economic and technical impacts of the trial specifically orienting this towards future visions around automation in the community, the ecology and autonomy of the commons. Participants were asked about their motivations for continued participation in the trial, and their views on potential incentives to stimulate community-wide participation in a larger-scale automation program. Household workshop discussions covered a range of topics (Table 2)

Following the conclusion of the workshop, follow-up surveys were conducted to generate householders' satisfaction with the communication received during the trial and their overall experience of participating in the trial. Transcripts from the workshop exercise were coded thematically in NVivo software. Using a thematic analysis (Braun and Clarke, 2006) the data was deductively coded by (i) participants' experiences with the cooling automation trial (ii) design preferences and challenges with the system (iii) opportunities and barriers to adopting cooling automation as a permanent feature at the household. Although analysis of the discussions is limited to this discrete Indian context, they still demonstrate a range of householders' responses to DR. It is important to note that our focus in this paper is the domestic interactions with the trial. Thus, in the next section, we present a summary of the technical findings from the trial and focus more on an in-depth analysis of our findings from the workshop.

5. Results

5.1. *Quantitative findings*

This section reports the quantitative impact of the AC DR trial on the energy consumption and electrical load of participating dwellings. Calculation processes were developed that allowed the baseline, aggregate energy and power demand of participating cohort of dwellings to be estimated based on weather data. This was compared to the measured energy and power demand during the AC DR trial to determine its impact. Details of these calculation processes are described in Appendix A. The degree of impact felt by householders on desired thermal comfort was evaluated; this being likely to influence the qualitative responses provided in the workshops and reported in Section 5.2. In addition to these relatively conventional analyses of demand response impact, the dataset was further investigated to construct cooling personas. These sought to describe households based on how they used their AC system at different times of the day and during the cooling season.

5.1.1. *Effect of dr ac trial on energy consumption*

The average, daily dwelling AC energy consumption was reduced because of the DR control. For the 12 days shown in Fig. 3, this varied from 139 Wh (7.1%) to 768 Wh (57.1%). DR AC control caused the dwelling's average daily AC consumption to fall from 1.73 kWh to 1.35 Wh, a reduction of 21.6%. This variation in demand was found to be statistically significant at 95% CI (ANOVA, F-value = 4.95; p-ratio = 0.05).

5.1.2. *Effect of DR AC trial on load*

As might be expected, the load reduction in each time block was found to be a function of the forecasted baseline load, i.e. the higher the AC load in any time block, the higher the reduction in load (Fig. 4). Considering all time blocks where control was imparted, the average load reduction achieved in the DAC field trial cohort during the period 19th to 28th May was 23%; from 0.144 kW per dwelling to 0.107 kW per dwelling (Fig. 5).

5.1.3. *Thermal comfort*

Evaluating the impact of the DR AC trial on household thermal comfort was compromised, as the dataset on internal temperature

Table 2
Selection of topics covered during the participant workshops.

Participants' awareness of when the AC system was switched off
How participants coped as indoor temperatures increased
Whether and what practices had to be adjusted
Whether there were non-negotiable periods for switching off AC systems
Impact of the technology on the sense of control over comfort
Technology distrust, data privacy and transparency (of technological objectives)
Whether they would be minded continuing to offer flexibility if the scheme could be extended

was not complete, beset by data collection issues and by householders unplugging the sensor because they required the socket for other appliances. Only six households out of the 30 participating cohorts returned internal temperature for a period covering both the baseline and the control period.

Thermal comfort in these six households was characterised by first identifying time windows (40-minute duration) where cooling had been requested. The average indoor temperature delivered in each identified window was then calculated. Frequency plots showing dwelling temperature across all active 40-minute time blocks for baseline and DAC control periods are shown in Fig. 6. The spread of achieved indoor temperature was broad, likely to be driven by several factors. For instance, time elapses between the AC system being switched on and the internal space reaching the desired condition, with elevated temperatures during this time lag contributing to an increased temperature range. It is likely that household practices were not consistent when AC was being used. For instance, the number of occupants, the amount of internal shading, and whether windows were open or occupants were cooking are all likely to have an influence on the speed at which the room temperature cools and whether the desired temperature set point was achieved. Different occupants in the household may also select different set points, and different set points may be selected at different times of the day or year.

Indoor temperatures achieved during DAC control periods were higher compared to the baseline period, with this difference statistically significant at 95% CI. The average increase in temperature over a 30-minute block was found to be below 1 °C in dwellings *a, b, e, and f* where AC usage was either *rare* or *timed* based on the cooling personas (Section 5.2.4). In dwellings, *c* and *d* (both *reactive* cooling personas) the temperature increase was 1.9 °C and 2.5 °C respectively. In these dwellings, AC usage appeared to be reactive, perhaps indicative of practices associated with guesthouse occupation, e.g. lack of familiarity with candidate AC control systems, less use of shading and lack of rigour in ensuring doors and windows were closed during AC operation.

5.1.4. Cooling personas

Cooling personas were derived by studying in each time block ($N = 30$ min) the T_A and the number of minutes the AC system was in operation (Fig. 2). Red indicated no AC use in this time block at this absolute temperature whereas yellow and green signified 50% and 100% AC usage respectively for the time period studied (Mar-Jun 2020). The heat maps visualise AC usage practice, e.g., trigger conditions for AC use at different times of the day, preferential AC use times and how dwelling AC use transitions as the climate moves from spring to summer. Using internal temperature data from the dwellings reported in Section 5.1.3, discrete cooling personas could be discerned by mode of AC operation, namely; use of AC system was *rare*, use of AC system was *reactive* to the climate, use of AC system was based on a *time* clock. For each of these cooling personas, households could be disaggregated by the AC usage, i.e. *light* and *heavy*. Utilising the data in this manner creates the possibility of assigning personas to households and then using these to infer the potential impact of future climate change on usage. Monitoring studies of a larger scale than reported here may yield the potential of linking personas to household meta-data presenting opportunities for targeting advisory on cooling practices, marketing flexibility programmes and developing bottom-up models of urban areas to evaluate the impact of both increased penetration of AC systems and future climate change on demand for cooling.

5.1.5. Summary of impact

The DR trials resulted in significant reductions in household energy consumption and power demand. From a network perspective, if replicated at scale they would allow large increases in cooling demand to be accommodated with no requirement for changes to energy supply infrastructure. Based on data from only a handful of dwellings, the quid pro quo for providing these reductions in the

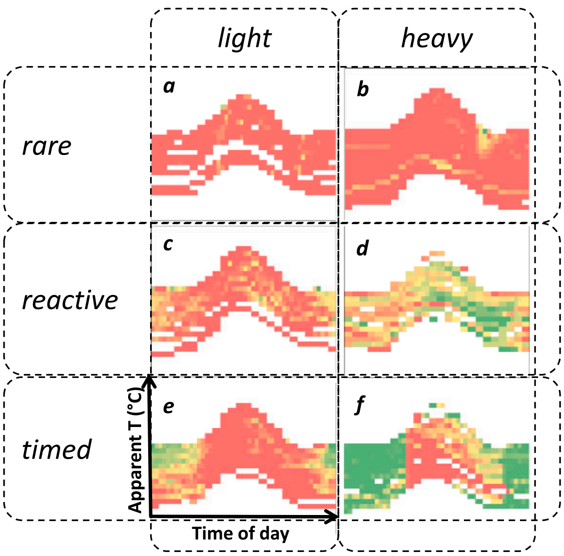

Fig. 2. Cooling persona matrix.

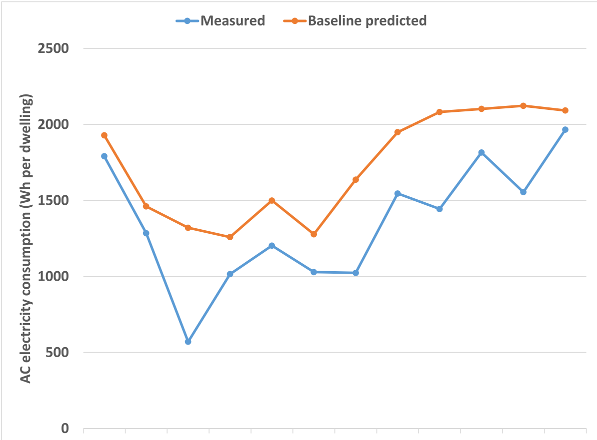

Fig. 3. Impact of DAC on aggregate AC energy daily energy consumption .

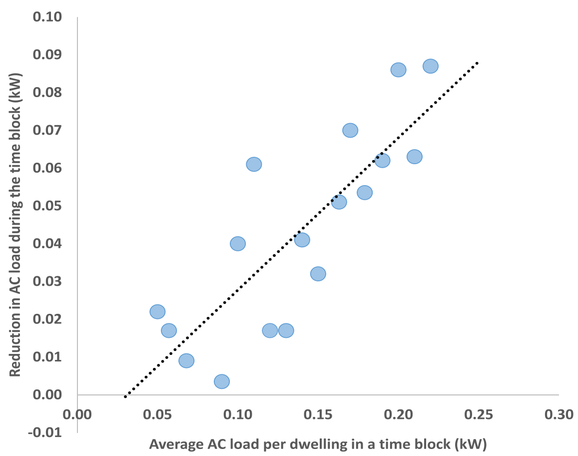

Fig. 4. Effect of predicted cooling demand on load reduction potential of DAC control . (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

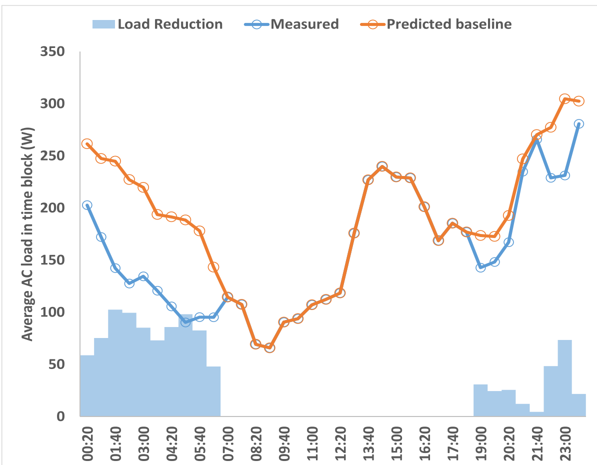

Fig. 5. Average dwelling AC consumption load shape – DAC control vs baseline .

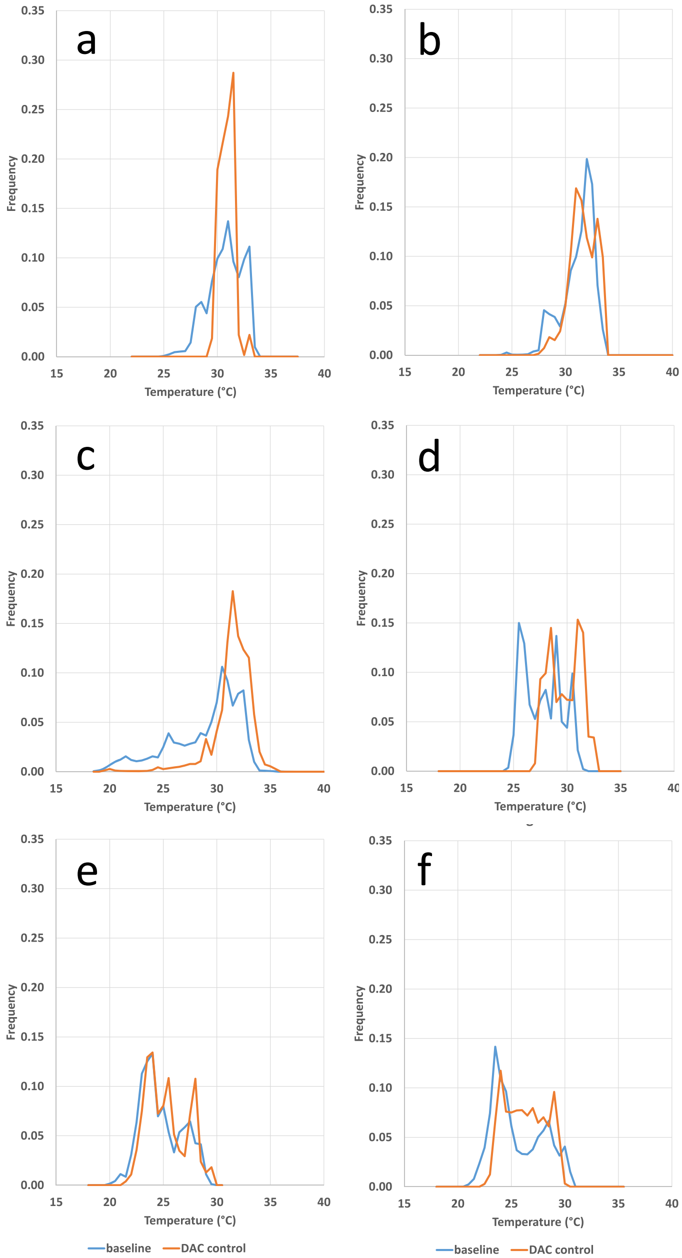

Fig. 6. Frequency plot of indoor temperature during AC operation for six dwellings – DAC control and baseline-.

form of impaired thermal comfort seems to be relatively slight, particularly for those households having cooling personas described as either *rare* or *timed.* If mechanisms could be devised that allowed the associated economic advantages to be socialised between recipients (energy network managers) and providers (households) it would be interesting to monitor participation rates given the status seen. The cooling personas point to households experiencing cooling technology using different practices with disparate results with respect to timing & duration of use as a function of weather conditions. As we will show in our workshop findings (Section 5.2), different materialities and subjectivities around cooling practices within the domestic shaped household relations to processes around cooling systems, control and automation. A more extensive trial would permit the evaluation of how and whether materialities/ subjectivities manifest themselves as cooling personas and how these are predicated on meta-data such as household formation and income level.

5.2. *Qualitative findings*

Based on workshop interactions, three categories of participating householders were observed: (a) those who accepted and engaged with the automation system, (b) those who engaged and overrode the system when in conflict with thermal needs and (c) those who engaged with the automation programme and shifted to other non-mechanical practices during control period to meet cooling needs. Recognising these different archetypes enabled the materialities underscoring actual household participation in automation to be recognised and the subjectivities that challenge the normalisation and/or exclusion of cooling automation within the home.

5.2.1. *Unpacking the materialities and subjectivities that shaped cooling automation in Auroville*

In Auroville, four main factors were found that captured materialities and subjectivities that influenced householders' interaction with cooling automation: (i) Shared material imaginaries around socio-ecological and biospheric use of energy (ii) subjectivities around the effect of extreme heat temperatures on householders' sense of comfort, (iii) subjectivities and trust issues around energy data and privacy governance (iv) the materialisation of cooling automation via communication and interaction with smart plugs.

5.2.1.1. The impact of shared material imaginaries around socio-ecological and biospheric use of energy in promoting householders' acceptance of automation. Research has shown that environmental identity or membership in pro-environmental commoning sites is a major predictor of an individual's performance of pro-environmental behaviours like energy-saving actions. The more an individual perceives their group to endorse biospheric values the more likely they are to support and adhere to the group's environmental identity and perceived values around energy savings (Sloot et al., 2022). Most of the participants in the workshop alluded to their own environmental identity and attributed this willingness to participate in the DR trial. As explained by Vimal "*when I heard about this project from Auroville consulting, I was very happy about it because power consumption and grid cuts have always been an issue here. So, it's interesting to see that such kinds of research studies are being done to automate and make energy consumption done in a better way in the community. And so, I'm very happy to be part of it. I've always been very inclined to projects which involve the environment, and I was quite excited about it when he came to install the control*." Vimal's comments were re-echoed by other participants and resonate with Fielding and Hornsey (2016) argument that individuals with a strong environmental identity not only strive to behave consistent with their self-perception and identity around environmentalism but are much more likely to be influenced, energised or guided by ingroup norms around environmental goals including sustainable energy behaviours.

Outside of the participant's signalling and maintenance of their environmental identities, we also found that shared imaginaries to support the community's collective goal of energy autonomy, reducing the community's environmental impacts and promoting sustainable energy consumption drove participants' willingness to accept cooling automation. Participants shared imaginaries were embodied as 'techno-biospheric ethics' and articulated in the following ways: (i) participants welcomed the idea of a longer cooling automation trial as they were highly concerned about individual and community-wide carbon reductions. Some argued that members of the community who were not part of the trial would likely take part in another trial due to the ecological consciousness of the community. (ii) Participants were also keen to see a reduction in power cuts and emphasised the social and community benefits of working together to reduce power outages and meet the needs of the local grid within Auroville. (iii) Some saw their participation in the trial as a means to further technological development around automation and displayed more enthusiasm for participating in future research projects around automation. This complements findings in the literature that suggests that when people think of themselves as group members, the group goals become internalised thus motivating members to behave in line with these goals (Fielding and Hornsey, 2016). As such, reducing electricity outages and minimising electricity waste were frequently repeated as motivations by participants in the study. Unsurprisingly financial incentives weren't deemed overly important, but it was noted by the participants that this can be attributed to Auroville's demographic which may not resemble mainstream preferences. Yet, they agreed that the main selling point for the adoption of cooling automation would be its impact on reducing costs and possible financial savings. This complements findings by (Johnson, 2020) in the UK, whose results also showed that householders' stated attraction to DR was the potential to save money.

5.2.1.2. Subjectivities around extreme heat temperatures on participants' sense of comfort. Despite the adoption of passive buildings in Auroville, subjectivities around the cooling needs of the body due to the continued rise in temperature and the frequency of climate-induced heat waves in India were a major source of concern amongst participants. How some participants reacted to the increase in heatwaves was moderated by the materialities of the design of their home, subjectivities around the age and tolerance levels of those living in the home and the activities carried out per time (see user personas in Section 5.1). For some, a combination of extreme heat and the need for comfort by younger children within the family led to the installation and more frequent use of ACs. As expressed here by Mel "I *have reluctantly had an AC for the past 4 years. I installed it when my daughter was studying for her A levels, and I am keen from an environmental point of view to minimise use*." This sentiment was shared by Yash who at the time of the workshop had an 8-month-old baby and suggests that due to the baby's needs "*the AC is well used*". Another participant, Deepak explained that "*I think the temperature was well maintained, but some of the kids were sick of it. The children felt it was warmer. It was not necessarily about the thermal sensation but because the system wasn't running. This to me was more psychological than physical*". The above quotes not only reveal the feelings and relationality of bodies in the home but also highlights how the increase in temperatures and its influence and connection with 'others' is integral to understanding how AC consumption comes to be configured in certain ways (see (Strengers et al., 2021) and why the attachment of automation might provoke negative emotional responses inimical to the goal of flexibility. Critically, it mirrors findings that young children can get in the way of providing flexibility, especially where the parents consent to such programs but the children undermine this effort by overriding the control. This echoes work on heating and care being non-negotiable (Butler et al., 2016; Shirani et al., 2017; Strengers et al., 2021) and reaffirms arguments that objects like ACs not only reveal and grease the constitution of social life but matter to some more than others.

To further understand participants' views around the impact of increasing temperature on their capacity to provide flexibility, we asked at which time of the day it was non-negotiable to reduce or turn off their ACs. Most of the householders had different preferences based on what type of AC users they were and their existing temperature setting threshold. Most said it was non-negotiable to turn off their AC at night, some were mid-day users while others were day and night users. Participants were asked if they were aware when their ACs were switched off during the trial and asked to reflect on what actions they took when this happened. Most householders reported that they weren't affected by the increase in temperature or didn't even notice when the AC was switched off. For those who noticed, the temperature increase was not a bother as they found new ways of adjusting or adapting to the changes. Only one participant noticed the increase and found it uncomfortable. Reflecting on behaviours adopted when the ACs were switched off and the temperature increase became uncomfortable, four participants admitted to overriding the control when the temperature increase became unbearable. The potential to override was linked to the time of day when householders found it non-negotiable to have their thermostats increased or ACs turned off. This was linked to periods when the indoor temperature was high with householders expressing a strong reaction to the loss of autonomy within the home. Four participants spontaneously turned on fans to compensate for the loss of comfort while a few left the control and tried to adapt to the heat. Those who chose to adapt often relied on non-technological coping measures such as managing the inflow of air by opening doors and windows. This is similar to (Nicholls and Strengers, 2018) findings on how embodied knowledge can lead to the adaptation of skills to address bodily experiences affected by temperature settings.

5.2.1.3. Subjectivities and trust issues around energy data and privacy governance. Subjectivities around trust and data privacy have been central to many arguments around the barriers to providing flexibility (Maalsen and Sadowski, 2019; Parrish et al., 2020). Trust is an essential 'feature [and a] norm that is strongly present in relational and economic exchanges' (de Wilde, 2020). It facilitates a reduction in complexity and serves as a mechanism that enables action despite uncertainty about the outcome of such actions or the future. In our study, participants acknowledged that cooling automation might easily be integrated into Auroville vis-a-vis existing subjectivities, rules and governance structures around AC use and energy consumption instituted by the local utility (Auroville Electrical services). Yet, they also highlighted the uncertainty involved in granting external utility access to their data. Participants were initially concerned with people having access to their data through the trial. However, this soon fizzled out once they realised the data was being handled by the local utility. As described by Chutu "*Data privacy was a concern in the beginning, especially for my wife. She wanted to know who was getting the data and what they were doing with it. You know, you have these sensors, you have these adapters, and you know, someone else is controlling it. So, it does play with the mind a little bit. It's a bit of an uncomfortable thing. However, we realised the benefits outweighed the negatives – and we were doing it for experiments that would potentially help us decrease our consumption. And I guess I'm just a little bit more relaxed about it because in the end, you know, I know it's for a better cause. In the end, it's like, yes, you know, the electricity consumption must be controlled. We need to kind of distribute it properly*". Some participants weighed the effects of data and privacy within the cost/benefit model of DR to the community. As shared by Bilu "*I have no issues with the data, I am happy to be part of a research project as the benefits for me and the community outweighs the negatives. The research project is something that I see could be in the future useful across India*". Others characterised data measurement from in-door temperature and AC as not being critical. As expressed by Raj "*Compared to what Google does, I think, what data are you collecting? You're just collecting information about my current consumption. And honestly, even though I try to bend my mind around it, I can't think of how you could misuse it even if you wanted to. So, it doesn't bother me at all. I don't think the data you are collecting is very critical, it is temperature and AC. What you gonna do with it?*". Participants' referral to the benefits for the community shows how existing subjectivities around the socio-ecological sustenance of the community can help formulate rules and negotiations around the circumstances by which automation might belong in 'the community.

When asked if the data controller were to change from their local utility (Auroville Electrical services) to a regional utility or was a bigger entity such as TANGEDCO, participants who previously had no data concerns changed their minds. Participants felt that data privacy and external control will be an issue in a bigger trial or a commercial setting. Participants' issues around privacy were centred on how the utility might exploit this data. Questions around ownership of the data were raised and participants felt data concerns could be addressed if issues of consent were central to the data collection process and if the data collected were open and assessable by householders. As automation is relatively new for householders, a large measure of trust is very pivotal and necessary, if householders are to cooperate and confront the risks associated with the increasing demand for ACs. As de Wilde (2020) shows, trust relationships are not just critical for the adoption of apparatuses like automation but also for the maintenance of their operations. Thus, locating participants' trust and confidence in automation systems and their respective institutional structures, seemed like a necessary and critical precondition for actionability on flexibility and the overall transformation of the energy system in Auroville. Understanding how such trust relationships can emerge, be leveraged, and sustained to build emotional connections with users will be critical for the deployment and scaling up of cooling automation as a transition pathway

5.2.1.4. The materialisation of cooling automation via communication and interaction with sensor technology. Amplifying the materialities of cooling automation in the home through communication is seen to bring cooling and energy use in general into greater awareness. In our case, participants opined that the level of information provided before, during and after the installation of the control system increased their curiosity and interactions with the system. Participants also alluded to the fact that the information on how the system should work, how and when the curtailment would occur, and the temperature set points helped them not only to identify when there was an issue with the system but also to mentally prepare for the curtailment. For most participants, cooling automation became meaningful when placed in relation to the desired aim of flexibility through communications.

We asked participants to share experiences around their interactions with the sensor technology. Two main issues were prevalent (i) most participants found the lights from the sensors distracting especially at night. As described by Piyush "*Initially I mean, I found it a little bit distracting to fall asleep. The light was blinking. It wasn't a major issue that was just within the first week we put a tape over it and that's taken care of. Secondly, I found that the software for the air conditioning wasn't very responsive. I tried a few times and we kind of reset this and tried to find out what was wrong. So, we had a hard time connecting mine. And it's not that it's an old AC, but I guess it just wasn't very compatible*." For this participant, cooling automation and its materialities became obvious through the interaction with the software and the need to gain control over the sensors to achieve sleep. (ii) like Piyush, other participants had issues with the mobile software deployed to control the AC from their phones. Most participants complained about the non-responsiveness of the software and how they often had to resort to the use of remotes. As observed by other studies (Carmichael et al., 2021; Kobus et al., 2015), technological glitches might dissuade further participation in trials. However, in our case, participants sought alternative ways of controlling the AC (e.g., ditching the app for the remote). This is antithetical to assumptions made in the literature around users abandoning technology at the first sign of a fault. However, we are also conscious that the decision to continue with the trial and not abandon it might have been moderated by participants 'techno-biospheric ethics' and membership in the intentional community.

Most participants were interested in how to make the system more responsive and provided recommendations on how to encourage householder interactions with the system. As explained by Mayan "*what I was saying is that it would be nice if the participants get to see everybody's efforts. How much savings I have made for the utility? It would also be nice for people to have a leaderboard kind of report because that will help us to share with future participants saying, this is what we tried, you can also give it a try*." This sentiment was also echoed by Suresh "*I think the technology should generally allow you to have a kind of feedback session. You can see how your house is responding, what contribution you've made and how your contribution and the impacts of your contribution from the perspective of the whole community that's participating so that you can see your role in it*". Participants need for feedback ties in with findings from existing literature that feedback may offer substantial benefits and encourage householders to support programs aimed at extensively reducing domestic energy consumption. Yet, as argued by scholars, healthy scepticism must be exercised around the scale of benefits that can be unlocked by providing DR-related feedback (Carmichael et al., 2021; Skjølsvold and Lindkvist, 2015).

6. Conclusion

Demand response programmes such as residential cooling automation are expected to have positive impacts on the decarbonisation, transition, and grid stability agendas of most countries. This is due to the cost, reliability, and flexibility resources that grid services can access through the domestication of automation as a dispatchable resource for grid balancing. But how do we unlock householders' acceptability of such programmes in the face of rising heat waves in places like India? We argued that commoning sites such as intentional communities prefigured by ecological dematerialisation are spaces that can provide important insights into how we might unlock householders' acceptability of automation. Drawing on critical materialist perspectives and through a six-month research trial on automation in an ecologically driven intentional community (Auroville), our main contribution was to materialise how cooling automation and its interactions with subjectivities that are internal (sensory and well-being) and external (heatwaves, membership in commoning sites) to the domestic shape householders' pliancy or rejection of such systems. Based on our theory and findings, we conclude that to unlock householders' acceptability of cooling automation in the face of rising heat waves, three themes are relevant for broader discussions around the role of cooling automation DR in transitions. We explore these themes below.

A conceptual shift in how we theorise the subjectivities that inform the interactions between apparatuses (ACs and automation), humans and the natural world: Much of the research around the role of automation DR have been largely framed within the dichotomy of service to grids and savings for households. Such bifurcations ignore the entrance of environmental and new climatic issues (heatwaves) within the home and how this will not only challenge householders' cooling needs, values, and ability to signal identities but potentially produce, and /or reframe domestic-environment relations. This socio-nature dimension will be critical for attaining ecological ambitions for our world. As such, we believe the materialist/commoning perspective helps us to transcend previous socio-economic imaginaries around DR as it envisions apparatuses like cooling automation beyond their current scope as sites of management/administration of human behaviour to sustain present-day capitalists' needs. Rather, it helps us to view them as part of socio-natures and commons — apparatuses that can potentially be reshaped by society-nature relations to promote the visions of a sustainable and equitable transition to post-capitalist societies.

Successful engagement with and scale-up of cooling automation depends on who controls the system and data: As seen from our findings, householders' engagement and the value attached to cooling automation are also dependant on factors such as who controls the data (local familiar utility vs. outside utility). While householders saw the value presented by cooling automation, they also suggested that this might create new techno-social problems (possible data leaks) within the domestic such as when critical household information is mishandled by an external utility. This is a valid trust issue as previous studies have shown how corporate interest in knowing, surveying, and changing what is done in and connected to the home (e.g., the consumer credit and advertising industry) have led to the use of intrusive schemes for compiling and cataloguing personal data (Sadowski, 2019) to benefit corporate interests. As argued by Maalsen and Sadowski (2019) automation mirrors the above patterns of data extraction through its sensing, recording, and analysing domestic energy use to enrol the home into a network of smart infrastructure. Now that such technologies have attracted corporate interests in the finance, insurance, and real estate sectors, who are into the monetisation of information, risk management, and asset maintenance; domestic users will likely become susceptible to products and services designed to not only induce behavioural modifications but also provide corporations with new data and methods for squeezing out financial obligations or enforcing digital discipline (Sadowski, 2019). If such data extraction activities are not curtailed through consumer protection policies, this will derail the deployment and scaling up of cooling automation as a transition pathway.

Finally, identifying the user personas that can shape technological configurations and market decisions around automation. We see an opportunity to understand traits and preferential periods that shape how apparatuses like ACs, and automation become integrated and shape everyday domestic routines. User personas are an untapped resource in behavioural-driven sustainability transitions research and policy narratives. We recognize, the limits of such an analysis, especially as it needs a large-scale analysis of various households to be able to concretely articulate and integrate user traits in developing, designing and implementing cooling automation programs.

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.

Data availability

Data will be made available on request.

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Appendix A. Calculation Methodology for Quantifying Trial Impact

Baseline AC consumption

Absolute temperature (T_A) was used to describe the external climate, more comprehensive than dry bulb temperature as it also contains terms for wind speed and relative humidity (VCALC, 2021). The minimum apparent temperature for the period was found to be 26.4 °C on 3rd March at 21h00 and the maximum was 38.4 °C at 11h00 on 12th May.

Daily average T_A was found to be highly correlated to the total daily average energy consumption of the participating cohort of households ($r = 0.88$; Pearson's correlation). A polynomial function was developed using T_A as the predictor variable (Eq. (A.1)) that was able to predict daily aggregate AC consumption with a mean absolute percentage error (MAPE) of 16.7%, satisfactory for forecasting purposes (Ostertagová, 2012). The polynomial function was used to estimate the AC consumption that would have occurred during the period when DAC control was in operation to permit baseline AC consumption to be estimated.

$$E_{AC} = 0.015T_A^2 - 0.403T_A \tag{A.1}$$

E_{AC} average aggregate daily AC consumption (kWh)
T_A daily average apparent temperature (°C)

Baseline AC Load

A similar process to that described in Section 7.1 was used to determine the Baseline AC load. In the first instance, the dataset was split into 40-minute time blocks, matching imposed DAC operational periods. The consumption data (kWh) was then converted into power (kW in each time block, with this power level effectively representing the average power load over the candidate 40 min. To estimate the baseline average power consumption over each of the 18 operational time blocks (i.e. 00h00 to 00h40, 00h40 to 01h20 etc.), a unique polynomial using T_A as the predictor was derived. In this manner, a time series of power demands at a 40-minute temporal resolution could be constructed using the series of polynomials. Whilst prediction accuracy was lower than that seen for daily AC energy consumption (MAPE averaging 40.1%), in only one of the 18-time blocks was a prediction with MAPE greater than the 50% returned, this being the threshold for 'good' prediction accuracy (Ostertagová, ibid).

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