

Affordable Multi-family Housing Occupant Experience: All-electric & Zero-net Energy Communities

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ABSTRACT

The environmental impact of the built environment has been an industry and political focus for decades. Building decarbonization - curtailing carbon intensity of the built environment - is a key part of California's strategy to achieve carbon neutrality. Given California's relatively clean generation portfolio and mild climate, building electrification has become a critical route to decarbonization. Affordable multi-family housing is also beginning to adopt lower-carbon designs, typically in response to the terms of their financing. Disseminating information on structural and technical aspects of lower-carbon buildings can facilitate industry adoption of advanced practices. User experience and occupant behavior are also important factors influencing the transition to lower-carbon housing, but they have received little attention. In a preliminary effort to address the gap in the literature, the present study aims to describe occupants' knowledge of, education about, and satisfaction with their lower-carbon homes within three affordable housing communities in California. Additionally, residents' perceptions of all-electric and zero-net energy (ZNE) buildings is explored. The three developments focused on differed in technologies employed, location, and size: Mutual Housing at Spring Lake in Woodland, California ("Spring Lake"); St. Paul's Commons in Walnut Creek, California ("St. Paul's"); and The Nightingale in Los Angeles, California ("The Nightingale"). Occupant satisfaction among residents was generally high, with differences among certain end-uses and aspects of these all-electric and ZNE communities.

Introduction

The building sector's total fossil fuel consumption accounts for about 29% of the United States' total annual greenhouse gas emissions (Leung 2018), and the environmental impact of the built environment has been an industry and political focus for decades. Recently, California has declared a goal of carbon neutrality by 2045, set forth by provisions of Senate Bill 100, and 2018 Executive Order B-55-18 (EDF 2021). Building decarbonization - curtailing carbon intensity of the built environment - is a key part of California's strategy to achieve that goal. For the purposes of this research, the phrase "lower-carbon housing" refers to communities that employ various advanced technologies to achieve reduced operational carbon emissions. There are several types of lower-carbon building designs, including all-electric, zero-net energy (ZNE), and ZNE-ready designs. The lower-carbon buildings highlighted in this work aim to achieve high energy efficiency, partial or complete electrification, and derive at least part of their power from on- or off-site renewable energy sources not derived from fossil fuels (e.g., solar, wind, and hydroelectric power). Typically, lower-carbon buildings emphasize electrifying end-uses that are otherwise gas-fired, especially space and water heating. Given California's relatively clean generation portfolio and mild climate, building electrification has become a critical route to decarbonization. Affordable multi-family housing is also beginning to adopt lower-carbon designs, typically in response to the terms of their financing.

As lower-carbon housing comes to the forefront of the building decarbonization effort, there has been substantial focus on development, construction, and operation of buildings (Christensen et al. 2005; Aldrich 2012; Springer and German 2015). Disseminating information on structural and technical aspects of lower-carbon buildings can facilitate industry adoption of advanced practices. User experience and occupant behavior are also important factors influencing the transition to lower-carbon housing, but they have received little attention. The lack of metrics to assess occupant experience in a rigorous way leads to practice that “fails to account for the diversity of socio-cultural understandings, the inhabitants’ expectations and their behaviours” (Williamson et al. 2010). Performance criteria, too, may underplay the importance of building occupant experience and behavior. For example, only 25% of the “credit intents” for the LEED for Existing Buildings: Operations and Maintenance™ rating system are associated with building occupants, according to Pyke et al. (2010).

Academic literature on occupant experience in and satisfaction with lower-carbon homes predominantly highlights market-rate housing developments in Europe and Australia (Mlecnik et al. 2012; Thomsen et al. 2013; Berry et al. 2014; Sherriff et al. 2018). Mlecnik et al. and Thomsen et al. show that satisfaction and comfort among occupants is generally high. Thomsen et al. also show a high level of “commitment and pride” among occupants towards their lower-carbon buildings. Occupants became more conscious of their usage and behaviors (Berry et al. 2014; Thomsen et al. 2013). Thomsen et al., however, note that this heightened awareness and knowledge did not necessarily translate to behavior change. Little has been documented about occupant experiences in lower-carbon homes in the United States.

Dissemination of information to occupants can be essential to shaping end-user experiences in lower-carbon housing (Mlecnik et al. 2012; Thomsen et al. 2013). For example, Thomsen et al. highlight that improper user interaction with unfamiliar technologies may lead to lower levels of satisfaction, particularly with space conditioning equipment. Mlecnik et al. additionally stress the importance of education regarding equipment operation for occupants, such as renters, who are not involved in the equipment decision-making process.

To the authors’ knowledge, there is no existing literature on resident experience in lower-carbon affordable housing in the United States. One United States-focused study by Langevin et al. (2012) explored the perceptions of energy usage held by residents of conventionally constructed public housing. Some residents reported low satisfaction with space conditioning. This was typically related to the need to use energy-consuming adaptations in winter, such as opening windows and running the air conditioning, to combat overheating since residents did not have control over the heating itself. These actions increase energy consumption, and in turn, utility bills. Among income-qualified residents, a variety of energy bill payment structures exist, including: direct payment by resident, payment by resident through a program/budget, or a supportive service (e.g., such as the Public Housing Authority), paying utility bills on the resident’s behalf. Langevin et al. noted that though residents who paid energy bills were sometimes more conscious of energy-saving adaptations than comfort, motivations for adaptations were only energy-saving focused to an extent, and there still existed a threshold in which achieving comfort trumped energy savings. The study also highlighted as a barrier to achieving energy consumption reduction in low-income housing the lack of home oversight and agency due to not owning their homes; some residents expressed willingness to try energy conservation measures such as EnergyStar appliances and programmable thermostats, but the occupants themselves are unable to adopt those technologies in their homes.

Mlecnik et al. (2012) note the importance of obtaining feedback from occupants to shape the lower-carbon housing industry as it gains market traction in the coming years. Specifically, Mlecnik et al. assert that reports of occupants' positive experiences (i.e., word-of-mouth communication) rather than "concept branding" may be more influential in adoption of lower-carbon housing. While lower-carbon technologies have the potential to benefit both residents and the environment, understanding the occupant experience is integral to ensuring advanced energy features suit occupant needs. This is particularly important in the context of affordable housing, where occupants do not explicitly choose the energy features of their homes. In a preliminary effort to address the gap in the literature, the present study aims to describe occupants' knowledge of, education about, and satisfaction with their lower-carbon homes within three affordable housing communities in California.

Community Overviews

The following descriptions of the three communities of Mutual Housing at Spring Lake, St. Paul's Commons, and The Nightingale summarize information presented in a concurrent study of developer perspectives, which was informed by internet sources (e.g., community websites and reports), and interviews with the development and asset management teams (Outcault et al. 2022). These community overviews are provided to contextualize the occupant experiences presented in this research.

Mutual Housing at Spring Lake

Mutual Housing at Spring Lake ("Spring Lake") is an affordable housing community in Woodland, California, located in the Central Valley (Mutual Housing California n.d.-a; Mutual Housing California n.d.-b). The 101 housing units are reserved for agricultural workers and their families earning 0 to 60% of the area median income (AMI). One unit is reserved for the property manager.

Spring Lake was built in two phases. In Phase 1, 50 apartment flats and 12 townhomes were built; Phase 1 construction was completed in 2015. In Phase 2, 39 two-bedroom apartment flats were built. Phase 2 was completed in 2019.

Spring Lake is an all-electric rental housing community. The property is certified as 100% Zero Energy Ready by the U.S. Department of Energy. The community includes electric heat pumps for both space and water heating, a 209-kilowatt solar photovoltaic (PV) system, LED lighting, and tenant energy usage monitors. Residents have their own solar generation allotment from the on-site PV system for which they receive credits from the local utility [Pacific Gas and Electric (PG&E)] proportional to the number of bedrooms in their unit. With the solar offsets, the energy model predicted that most households would have very low electricity bills (i.e., under \$10/month).

Spring Lake has implemented several energy-related education and outreach programs for their residents. Upon move-in, residents of Spring Lake receive a binder with educational information on the green features of their community and are walked through the information in an educational session, either with a large group during a lease-up event, or individually with management or a community volunteer upon move-in. There is also a Green Leaders program, a voluntary group for residents to share information about green lifestyles, including topics such as recycling and meter reading. Residents in the Phase 1 development were provided technologies

that promote learning about and conserving energy, including smart showerheads to encourage shorter showers, a home energy monitor (the “Canary” device), and a smart power strip.

St. Paul’s Commons

St. Paul’s Commons (“St. Paul’s”) is a mixed-use community development in Walnut Creek, California (RCD n.d.). The community sits on land owned by and adjacent to St. Paul’s Episcopal Church. Construction of the residential units was completed in 2019 and they were fully occupied by April 2020. St. Paul’s has 45 residential units, including 30 studio units, 14 one-bedroom units and one two-bedroom unit reserved for the property manager. The ground floor of the building features a community space, operated by St. Paul’s Episcopal Church and the Trinity Center, a drop-in service center for homeless and working poor adults. The space includes a commercial kitchen, laundry, and shower facilities.

Occupant incomes range from 30% to 60% of the area median income. In addition to income restrictions, half of the units serve as fully supportive permanent housing for individuals who have special needs, have experienced homelessness, or are living with HIV/AIDS. Supportive housing refers to communities that provide both living space and on-site social services for individuals of populations that experience a range of conditions and experiences, including homelessness to mental and physical health necessities (Dohler et al. 2016).

St. Paul’s is a Green Point Rated Platinum, all-electric building featuring an on-site solar PV system and high-efficiency centralized heat pump domestic water heating. Packaged Terminal Air Conditioner (PTAC) units supply heating and cooling to all 45 units and are supplemented with mini-splits in the one-bedroom and property manager’s units. A packaged terminal air conditioner, or PTAC, is a commercial grade air conditioner that is installed directly through a wall (Sylva Inc. n.d.). Mini-splits, or ductless split system air conditioners, are multi-component devices that provide effective cooling, and many times heating, to specific rooms that lack existing ductwork (Sylva Inc. n.d.).

Management did little in the way of resident engagement concerning St. Paul’s advanced energy features. The fact that the building is all-electric is not prominently featured on their website or in other outreach materials. When asked, the individuals interviewed speculated that the lower-carbon design of the building was of little importance to the residents (Outcault et al. 2022). A member of the property management team said that she always mentions to residents that the building is all-electric but that many do not seem to care. Mostly, they are just thankful for a home, as the majority of residents had been homeless before moving into St. Paul’s.

The Nightingale

The Nightingale is a supportive housing community in South Los Angeles, California (Link Housing Corporation n.d.). Construction was completed in July 2019. The Nightingale’s 30 units include 29 one-bedroom units and 1 two-bedroom unit designated for the property manager. For residents with disabilities, there are 15 Universal Design units. Occupant incomes range from 23% (3 units) to 30% (26 units) of AMI. Units are reserved for individuals with direct referrals from the Los Angeles County Coordinated Entry System (CES) and Department of Health Services for those meeting homeless requirements. All resident units are intended for single or double occupancy, not families.

The Nightingale is a LEED Gold certified, ZNE-ready community featuring an on-site solar PV system. All end-uses are electric except for water heating, which uses gas boilers.

Residents are responsible for electricity bills, but refuse, sewer, water, and water heating are included with rent. Resident services focus on housing stability and creating a community of support.

The research team was not able to collect information on the operation and performance of the building. No resident engagement activities were conducted to introduce occupants to the energy features of the building. According to the development team, because all the occupant-facing in-unit technologies were typical for affordable multi-family housing units, there was no need for resident engagement regarding building operations.

Methodology

Researchers conducted a survey of residents to capture occupants' experience, particularly in relation to the building energy features of Spring Lake, St. Paul's, and The Nightingale. One adult member of each household, 18 years or older, was eligible to participate. The survey instrument was programmed in Qualtrics software and surveys were conducted via telephone in English and Spanish. The survey took 10-30 minutes and participants were compensated with a \$25 gift card, which was distributed afterward by onsite property managers or mailed directly to participants by the research team.

Questions in the survey covered topics including both overall and specific end-use satisfaction; knowledge, attitudes, and perceptions of the installed energy efficient technologies; and what, if any, education was provided to residents. Information on energy bills was also collected. Exclusive to Spring Lake Phase 1 households, residents were asked about their use of the Canary Feedback Device installed in their units.

Results

The results of the survey are reported according to the survey sections. In total, 82 participants were surveyed across the three communities. This included 16 participants from The Nightingale (55% response rate), 52 participants from Spring Lake (52% response rate), and 14 participants from St. Paul's (32% response rate). While respondents' ages ranged from 18-80+, half the respondents were in their 50s (24%) or 60s (26%). The respondents' sex was almost evenly split, with slightly more female respondents (55%) than male (45%). A majority of respondents took the survey in Spanish (61%) and the remainder in English (39%). Sample sizes vary by question because some questions are community-specific, and others were displayed only if certain responses to previous questions were given.

Knowledge

The survey assessed participants' knowledge and awareness of several key energy features of their buildings. Specifically, participants were asked to identify whether their communities had an onsite solar PV system and gas service. They were also asked whether they had heard their communities described as "all-electric" (in the case of Spring Lake and St. Paul's) or "zero-net energy" (in the case of Spring Lake and The Nightingale). As a reminder, all three communities had solar PV systems; Spring Lake and The Nightingale were ZNE/ZNE-ready; and The Nightingale was the only community with gas service, which powers the

community's central water heater. Figure 1 presents the proportion of respondents in each community that correctly identified the presence or absence of each technology.

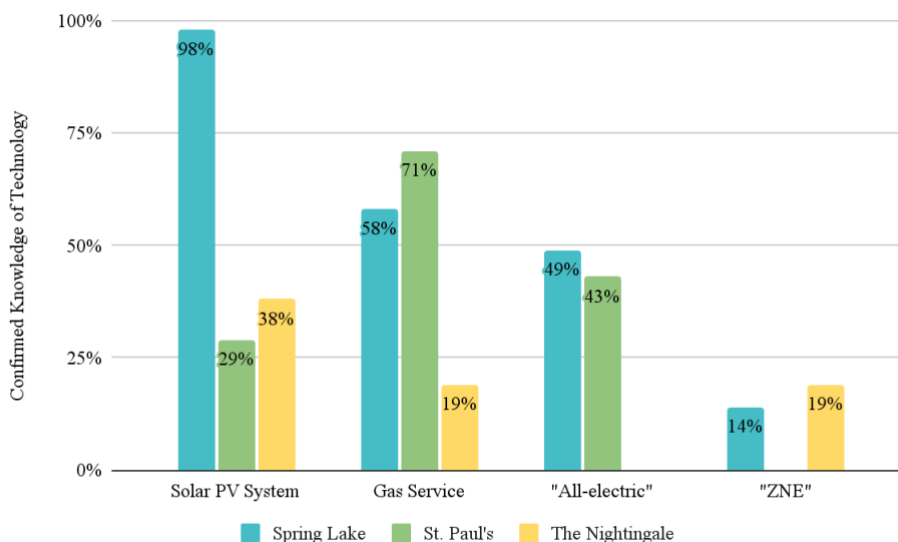


Figure 1. Percentage of respondents who correctly identified the presence or absence of a solar PV system and gas service in their communities, as well as correctly identifying their community as “all-electric” or “ZNE”.

Across communities, 74% of respondents indicated that their community had solar panels. However, there were statistically significant differences among communities' awareness [$\chi^2(4) = 42.25, p < .001$]. Nearly all respondents from Spring Lake were aware of the community solar PV (98%), compared to only 29% and 38% from St. Paul's and The Nightingale, respectively.

Across communities, 52% of respondents correctly identified the presence or absence of gas service, though again awareness differed significantly between communities [$\chi^2(4) = 11.60, p = .021$]. A majority of respondents from Spring Lake and St. Paul's (58% and 71%, respectively) correctly reported the absence of gas service in their communities while only 19% of respondents from The Nightingale correctly identified that their community did, in fact, have natural gas. However, less than half of respondents at both Spring Lake (49%) and St. Paul's (43%) reported having heard of their communities referred to as “all-electric”. The term “zero-net energy” was even less familiar. Those who identified their building as “all-electric” were asked to describe their understanding of the term. The majority of respondents mentioned the absence of gas and/or that all appliances were fueled by electricity. A few incorrectly equated “all-electric” with the on-site solar generation.

Similarly, those who identified their building as “zero-net energy” were asked to explain what “zero-net energy” means. Most commonly, residents reported that they did not know. Other comments revealed a partial understanding or misunderstanding, often conflating ZNE with the idea of renewable energy sources, particularly solar (e.g., “not using any fossil fuels besides solar and wind”; “only use solar panels”); or generally stating that it saves energy. Only one resident described the concept of balancing energy consumption and production, e.g., “what is extended out gets put in, or what is put in gets extended out, so that is if I need 10kW and I use 10kW ... then that will be replaced by the solar system.”

If respondents in ZNE or all-electric communities had not heard their community referred to in these terms, the interviewer gave a definition of the relevant term and then asked whether the respondent thought the term characterized their community. (E.g., “All-electric buildings are ones that run on electricity alone. They have no gas service. Do you think [Community Name] is all-electric?”). When prompted in this way, an additional 29 respondents across the two all-electric communities (40% at Spring Lake, 57% at St Paul’s) said they thought their community was all-electric and an additional 34 respondents across the two ZNE communities (56% at Spring Lake, 31% at The Nightingale) said they thought their community was ZNE.

Education

Respondents who correctly identified (without prompting) that their community has solar panels (61 residents), or that they have heard their community described as “all-electric” (43 residents) or “ZNE” (12 residents) were asked how they learned of such energy features (Figure 2). The most common way (51%) residents learned about their building’s solar PV system was through observation (i.e., they saw the PV panels on the roof). The most common way residents learned their community was ZNE or all-electric was through verbal communication from management, either during a resident orientation meeting (most common for ZNE) or individually (most common for all-electric).

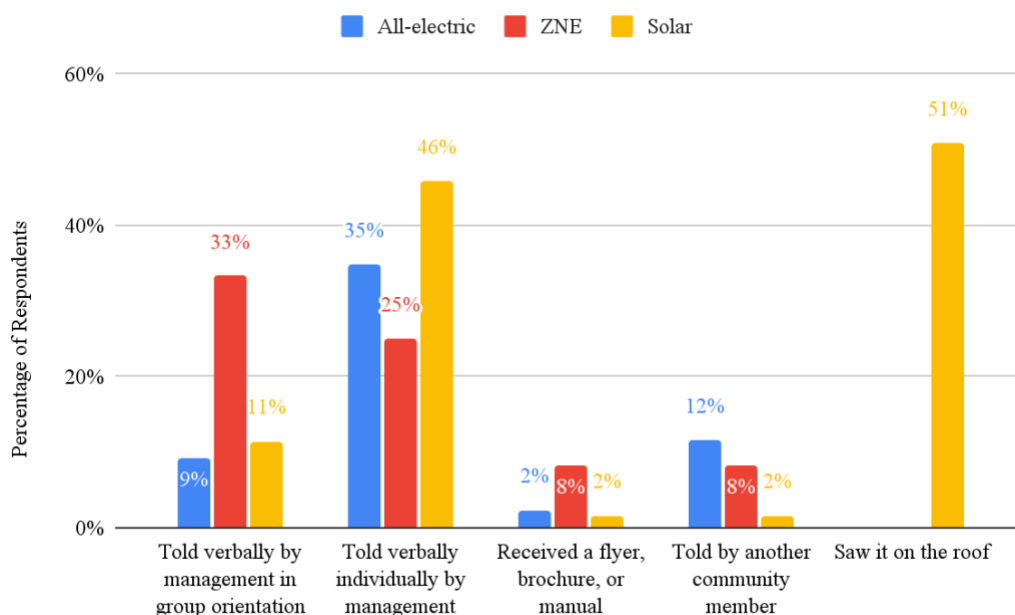


Figure 2. Percentage of respondents who learned of the lower-carbon status and solar PV system via each communication method. “Saw it on the roof” was only applicable to solar panels.

The survey also asked residents if they had received information on various energy features within their units. Overall, residents across communities most commonly reported receiving information about heating (51%) and cooling (59%) systems. A slight majority of Spring Lake residents (52%) also received information about their dishwasher. Education regarding water heating was least common overall (20% across communities).

Roughly half of respondents (48%) said they wished they had more information about their building's energy features or appliances, the solar PV system, or the "all-electric" or "ZNE" status. While many simply stated that they wanted to know about "everything", others gave detailed examples of the information they would like, including how the solar panels work so they could assess their energy bills and how to do basic maintenance on their appliances (especially when they break down). Several respondents also reported wanting more information on how to adjust the thermostat to maintain a fixed temperature.

Attitudes and Perceptions: Solar, All-electric, & ZNE

To gauge sentiments about lower-carbon housing features, respondents were asked how they felt about living in a community that has solar energy ($n = 82$), is powered only by electricity ($n = 58$), and/or has ZNE goals ($n = 43$), as applicable to each community. Respondents were prompted for opinions based on which community they lived in, as well as previous answers to knowledge questions. Specifically, if respondents were aware of the ZNE or all-electric status of their communities (either initially or after being provided with a definition) they were asked their opinion on those building features.

Solar energy. Most respondents felt positive about living in a community with an on-site solar PV system. When asked to explain, financial benefits proved to be a strong influence for roughly one third respondents. One explained she "went years without paying" energy bills due to their allocated solar credits. Just under 10% of respondents cited environmental benefits. They offered comments like: "I wish all buildings had solar panels. Not using fossil fuels" and "Ayuda más, contener contaminación, controlar la energía, no usan otro tipo de energía" (translation: "It helps more, curbs pollution, controls energy, and it doesn't use another kind of energy"). Four respondents mentioned energy efficiency. Two touched on technological growth, explaining they were in favor of solar energy because "it is a good technological advancement," and, "it is something that is progressing. I feel like I am up to date." Another touched on energy independence and resiliency: "There was a time when there was an outage and we were left without electricity for a while, but others who did not have solar panels were left without energy for a longer time." One respondent, however, felt slightly negative about living with solar panels, noting energy conservation and low bills were a good thing, but that they might result in a perverse incentive: "not sure if, because bills tend to be cheaper, people use more energy than they should. They are maybe more careless." The few who did not feel positively said it did not affect them or they were unfamiliar with how it works.

All-electric buildings. Most respondents felt positive about living in an all-electric apartment. Many respondents appreciated electricity as a safer energy source than gas, e.g., "Gas is dangerous. I feel safe knowing there won't be an explosion or the smell of gas"; "You don't have to be afraid especially when you have kids"; "It's cool, I don't have to worry about turning the gas off and fire." Others noted that "gas has gotten very expensive" and that their energy bills in their all-electric apartment are low. Those ($n = 3$) who had a negative perception of all-electric power cited their preference for cooking on a gas stove and having gas appliances available during power outages: "Because when there's no electricity, we can't use anything at all."

ZNE buildings. A slight majority felt positive about living in a ZNE building; however, a significantly smaller proportion of respondents felt positive about ZNE compared to all-electric

($z = 2.12$, $p = .034$) and solar ($z = 3.56$, $p < .001$). Respondents highlighted general environmental benefits of ZNE (e.g., “good for the environment”; “not contributing to the pollution”; “I suppose it helps the planet”), reflecting varying degrees of understanding (e.g., “I don’t know the difference, but I imagine it is good for us”). Some conflated ZNE and all-electric (e.g., “it is better for us and the environment. Especially since gas disproportionately affects people of color and using natural energy is better for us”). Some respondents attributed positive feelings about ZNE to the potential savings on utility bills, which one remarked is “especially [important] being a single parent”. Nearly half reported neutral feelings about ZNE, citing a lack of knowledge or personal relevance, e.g.: “I don’t really know how it affects me”; “I don’t understand what it means”; “It makes no difference in my life”.

Energy Conservation

Respondents were also asked about their attitudes regarding energy conservation. A large majority of respondents felt that energy conservation was either very or somewhat important (98%), liked the idea of helping to make their community more efficient and sustainable (99%), and felt like their individual efforts to save energy impact the overall community and world (81%). When discussing the importance of energy conservation, respondents cited environmental, social, and financial benefits.

Regarding environmental benefits, various respondents cited global warming, noting that energy conservation can “contribute to the wellness of the environment and address global warming,” by reducing emissions and pollution. One respondent elaborated, “We are destroying this world. It’s gotten worse. We need to stop that and reverse that effect ... because we will have serious problems if we don’t.” More than one respondent discussed energy scarcity, and disapproved of wastefulness.

The condemnation of wastefulness was also connected to social responsibility and blackouts in other respondents’ comments. One respondent lamented, “People are so wasteful. We have so many incidents with weather and other things that could probably be minimized if people were more aware.” Another mentioned that energy conservation is important to “avoid blackouts like the one we had last year. Without electricity we cannot do anything.” In hopes of a collective effort, one respondent said, “If we all try to save energy, then there won’t be many outages.”

Altruistic statements of social responsibility were also made, including, “[Energy is] a resource that a lot of people need, and we must be aware of how much energy we are using,” and, “there [are] probably other people that need it more” (in regard to individuals using medical devices). Others noted an obligation to protect the environment and keep it intact for subsequent citizens of the planet. One stated, “It’s our world and we need to take care of it, otherwise our kids and grandkids aren’t going to have it.” Another respondent remarked, “Sometimes we don’t know how to measure the consequences for future generations. It is important that we take care of our planet for us and for those in the future.”

Canary Feedback Device

The Canary is a plug-in energy feedback device that communicates information to users about both instantaneous and cumulative energy use. A light on the left side of the monitor reflects instantaneous energy demand; it glows green when demand is below average, amber for average, and red for above average instantaneous energy consumption. A light on the right side

of the monitor reflects cumulative daily energy consumption, beginning at midnight and ending at 11:59pm (for a 24-hour span); the light begins as green and turns amber as a warning, then red if usage exceeds the daily consumption budget based on each household's allotted solar credits. If households can keep within their solar credit budget on a monthly basis, they should not owe anything for their electricity usage. The Canary was implemented only in Phase 1 units of Spring Lake (62 units).

Most Phase 1 respondents (74%) reported that they had a Canary. Of those respondents who had a Canary ($n = 36$), 56% checked it at least once per day when they first moved in. At the time of the survey, 42% reported that they still check it at least once per day. A Wilcoxon Signed-Rank Test indicated that the median frequency of use was not significantly different at move-in compared to current (time-of-survey) ($Z = 35$, $p = 0.27$), suggesting persistence in usage patterns.

Of those respondents who reported using the Canary ($n = 31$), 68% reported that it helped them learn that certain items in their home use a lot of energy. When asked about the usefulness of the Canary, most (81%) reported some benefit, including increased awareness (e.g., "I am more aware of the amount of energy I use"), education (e.g., "It helps me understand my bill when it is higher than I expect"), motivation to conserve (e.g., "It worries me when it turns red so I start being more careful about how much I am consuming, especially during winter when I cook more often"; "it keeps us accountable") and energy bill savings ("I can limit the consumption and that way it helps me save money"). Of those who did not find the Canary at all useful (39%), some reported not understanding the information (e.g., "I don't know what each color means"; "Throughout the day it is green and at the end of the day it turns red which makes no sense. It is probably broken").

Of those respondents who reported using the Canary (either when they first moved in and/or at the time of the survey; $n = 31$), 29% reported that they had changed the way they use energy in their home as a result. Specifically, some users reported that the Canary's red light prompted them to turn things off or unplug devices, whereas others seemed to have developed a new habit of turning things off and unplugging devices when not in use (unprompted by the device). Some noted changes they made with respect to specific activities or devices, e.g., using plug strips, modifying cooking practices, and using natural lighting.

Energy Bills

Figure 3 presents respondents' experience with their energy bills. Samples sizes for this question were reduced because some residents do not receive energy bills due to enrollment in financial assistance services. Experiences varied widely both across and within communities. A majority of respondents from The Nightingale ($n = 7$) and Spring Lake ($n = 46$) reported that their energy bills were lower than they expected. Residents from St. Paul's ($n = 14$) were more split, with roughly one-third reporting "About the same", "Higher", or "Lower" than expected. Those with higher bills than expected didn't have much insight as to why that was. Respondents with lower bills than expected frequently attributed their lower bills to the on-site solar generation.

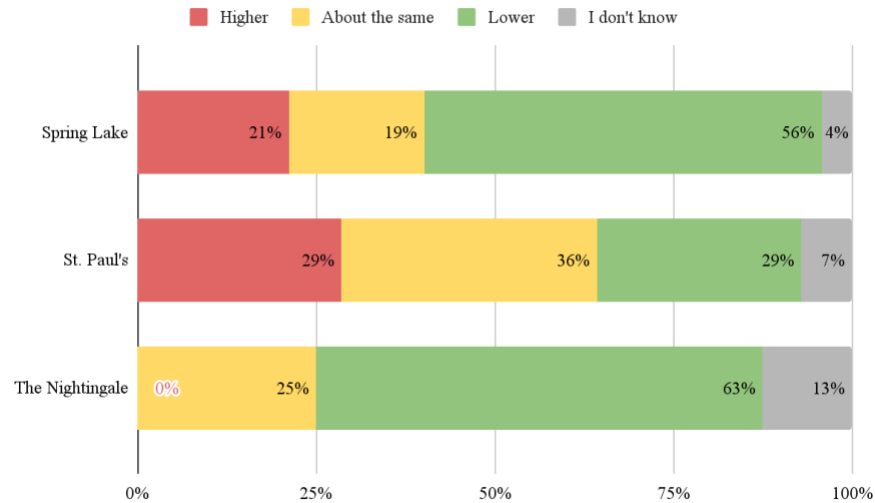


Figure 3. Responses when asked if energy bills were higher, lower, or the same as expected.

Satisfaction

Across communities, the vast majority of respondents (96%) were somewhat or very satisfied with their apartments overall (Figure 4). In terms of specific technologies, a majority of respondents across and within each community were satisfied with the air conditioning, heating, hot water, air quality, lighting, and number of electrical outlets provided in their units. In terms of differences between communities, a significantly smaller proportion of respondents from St. Paul's, which has PTAC units, were satisfied with air conditioning [$\chi^2 (2) = 6.09, p = .048$] and heating [$\chi^2 (2) = 10.58, p = .005$] compared to one or both of the other communities. Other differences in satisfaction (e.g., water heating, air quality) were not statistically significant.

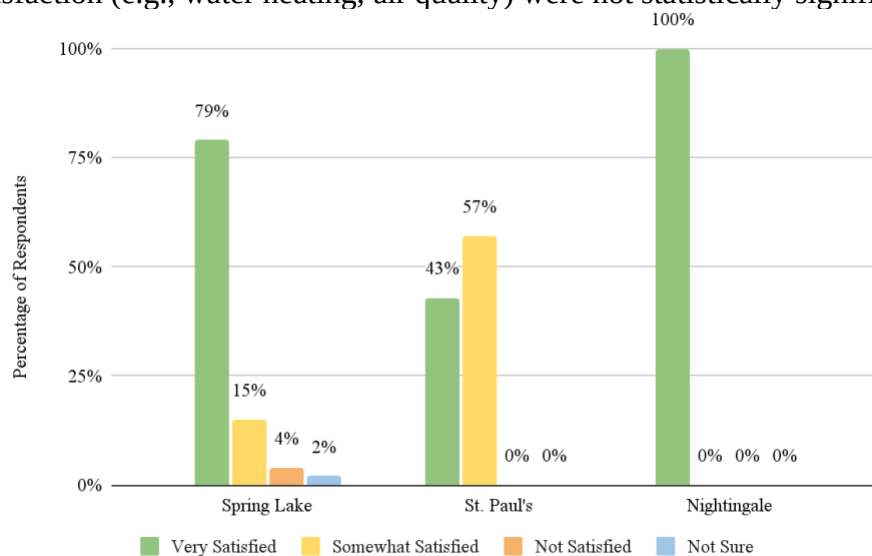


Figure 4. Overall satisfaction with apartment, by community.

Discussion

The results of this study indicate that occupant experience with lower-carbon affordable multi-family buildings is generally positive, consistent with previous studies on market-rate lower-carbon housing (Mlecnik et al. 2012; Thomsen et al. 2013). Despite some differences in installed technologies, most respondents were generally satisfied with the energy equipment. One exception is air conditioning; notable differences in satisfaction were evident across different space conditioning technologies. St. Paul's residents, who had PTACs alone or in combination with mini-splits, were significantly less satisfied with their air conditioning than residents of the other communities that used heat pumps or mini-splits only. Interviews with staff involved with St. Paul's corroborated this finding saying that there were issues with PTACs adequately cooling to achieve comfortable thermal conditions (Outcault et al. 2022).

By contrast, most occupants surveyed were satisfied with water heating, with no significant differences across the particular water heating technologies installed. This is an important point in support of electrification since electrifying water heaters remains one of the main technological changes in building electrification (Dennis et al. 2016; Raghavan et al. 2017; Deason and Borgeson 2019).

Awareness of the key energy features of these communities (solar, all-electric, and ZNE) was generally low among residents. In general, residents were more aware, and felt more positively, about energy features in their community that they could see and understand. A significantly greater proportion of residents (virtually all) at Spring Lake were aware of the community solar PV compared to the other two communities, likely due at least in part to the extensive community engagement efforts at Spring Lake, as well as perhaps greater visibility of solar panels there (56% of residents said they learned about the PV because they saw in on the roof, compared to less than 10% – only 1 resident – at each of the other two communities).

Respondents were largely aware and appreciative of solar and all-electric power. Generally, respondents appreciated solar PV for the reduced electricity bills it supported, and all-electric construction for the safety benefits. A large majority of The Nightingale residents incorrectly assumed their community was all-electric, presumably because all in-unit appliances are electric, residents do not receive a gas bill, and they were not aware of the gas-powered central water-heating system. ZNE was the least known, and least popular, design feature; not understanding, or misunderstanding, this more complex concept was common. Low awareness of ZNE at Spring Lake was surprising given Mutual Housing's outreach and education measures, which were widespread enough to create false expectations of free electricity service, albeit unintentionally, for some Phase 1 residents. This led Mutual Housing to avoid advertising Spring Lake Phase 2 as "ZNE" during their lease-up process, which could partially explain why many residents were unaware of that designation. (It should be noted, however, that the community's website still uses the term.) Awareness of another abstract energy concept, phantom power, was also low across communities.

These results highlight important opportunities for resident engagement in lower-carbon buildings, similar to findings in the literature (Mlecnik et al 2012; Thomsen et al. 2013), even if such engagement does not significantly influence occupant satisfaction. For example, ZNE buildings may need to educate occupants to ensure that behavior aligns with modeled expectations and ZNE operation is achieved (i.e., consumption equaling renewable generation on an annual basis). Many respondents did report a desire for more information on both in-unit appliances and the on-site solar PV systems, as well as the "all-electric" and "ZNE" descriptors

of their respective buildings. Furthermore, residents' attitudes about energy conservation were overwhelmingly positive. This suggests there may be additional opportunities to educate and motivate residents to conserve energy, either to reduce their bills or their environmental footprint (or both).

The Canary energy feedback device provided in Phase 1 of Spring Lake is an important example of occupant engagement, with room for improvement. This intervention was successful by some measures, but not others. Energy feedback has a notorious novelty effect (Hargreaves et al. 2013; Buchanan et al. 2015), but Spring Lake residents' reported use of the Canary did not decrease significantly over time. A larger sample size may have indicated otherwise. A majority of Canary users said the feedback was helpful, particularly by increasing awareness of high-demand appliances (such as kitchen appliances). However, only a minority reported actually changing their behavior in response, perhaps because the energy-intensive activities signaled by the device were essential practices, such as cooking, offering little opportunity for change. The Canary's instantaneous demand display did not help residents identify base and phantom loads that might be reduced, since such devices were always plugged in. It is likely the Canary could have been more effective if paired with an in-home training component where residents were taught to unplug or use smart strips to power down all their devices on standby to lower their bills. Instead, Canaries were not installed in Phase 2 of Spring Lake.

Occupants may gauge utility bill expectations based on information provided by management, previous utility bills at other residences, or a lack of either. Some occupants from St. Paul's and The Nightingale were previously homeless, and therefore may have had very little reference point for expected energy bills. Additionally, for several years after opening, Spring Lake advertised that residents of their community can expect zero utility bills. The majority of respondents across communities had utility bills either in line with or lower than their initial expectations. This finding would seem to refute the notion that electrification raises energy bills for the most energy burdened (Bryce 2020), though more rigorous data collection on energy bills is required to definitively answer that question.

Limitations

Despite indications of initial setbacks with improper equipment installation, such as water heating and solar panel credit verification (Outcault et al. 2022), residents reported overall satisfaction with their units, energy features, and communities. It is possible that population demographics drove high satisfaction levels; formerly homeless residents and residents in supportive housing may have different perceptions of what conditions are acceptable and appropriate for their living situation. Additionally, since all three communities considered in this study are affordable multi-family housing, there is limited generalizability to affordable single-family lower-carbon homes and market rate multi-family housing.

Future Research

Future research exploring occupant experience in varying types of affordable multi-family housing is needed. For example, communities in this study housed formerly homeless individuals and agricultural workers, and offered permanent supportive housing for those with broader needs. Studying populations with different demographics will help formulate the body of knowledge of occupant experience in these housing communities. Additionally, studying residents' experiences with different types of lower-carbon housing (e.g., market rate vs.

affordable, all-electric vs. ZNE, single- vs. multi-family) will broaden understanding of occupant experience and shed light on potential differences across various housing types and levels of resident engagement with lower-carbon features. Understanding occupant experience offers vital inputs that can inform the design of lower-carbon buildings to ensure occupant comfort and satisfaction. This in turn is expected to encourage voluntary adoption and the political will to adopt lower-carbon building standards.

Conclusion

Constructing lower-carbon housing, especially all-electric and zero-net energy buildings, is an important component of California's efforts to decarbonize. General industry concern regarding building all-electric and zero-net energy buildings has included speculations about occupant experience and satisfaction, and consumer willingness to purchase these homes, in the case of single-family homes (Outcault et al. 2021). As part of a larger project, this study explored occupants' experiences of all-electric, and zero-net energy affordable multi-family housing by surveying residents of three communities across California. Residents from Mutual Housing at Spring Lake, St. Paul's Commons, and The Nightingale who elected to participate in this study were asked about their overall satisfaction, knowledge, education, attitudes, perceptions, energy bills, and energy use feedback device (for participants from Spring Lake). Respondents reported varying degrees of knowledge and information about lower-carbon housing and end-uses. Nevertheless, they were largely satisfied with energy bills and the energy features of their homes. Most respondents had a positive perception of on-site solar PV systems and the concepts of "all-electric" and "zero-net energy" housing. Many supported energy conservation and expressed interest in learning more about the energy features of their homes and ways to save energy. The majority believed their actions can make a difference. Together, these findings suggest that lower-carbon affordable housing may complement many residents' environmental and financial goals and that there may exist further opportunities to engage them in the clean energy transition.

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