Harmonized Resilience at Roosevelt Village: How Futuristic Grid-Interactivity and Resilience Come Together in Senior Affordable Housing

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ABSTRACT

To decarbonize the buildings and electricity sectors at a pace consistent with state and national climate goals, buildings must become grid resources, capable of morphing load profiles to accommodate variable renewable generation, facilitate cost-effective grid decarbonization, and help ensure reliable power system operation. Simultaneously, the changing climate poses increasing risks of extreme weather events and resulting power outages that developers, designers, and building operators must plan for. This yield s new questions around the best approaches to achieve these outcomes, what it costs, who benefits, and what barriers there are to widespread adoption.

We seek to answer these questions by adopting a futuristic set of grid-interactive design requirements for a mid-rise affordable housing, mixed-use development: to sustain critical loads during an outage and to consume no grid electricity for residential end-uses between 4-9pm every day. We present an approach that achieves these requirements, working to decarbonize the grid and maximize resilience for the facility and its residents while also addressing shortfalls in housing supply. Our work includes detailed building energy and economic optimization combined with construction cost analysis and carbon impacts. We find that achieving the requirements comes at a ~5% cost premium, an amount not likely to be acceptable for affordable housing under current policies and industry standards. We then generalize our design into a replicable 'recipe' to optimize the integrated use of distributed energy resources and explore the challenges to widespread adoption. We suggest many barriers could be overcome with policy changes that would bring benefits to under-resourced populations and society as a whole.

Introduction

Unlocking efficient, demand-side flexibility in the US building stock is critical to achieving a reliable grid and affordable energy transition, with estimates of savings up to $107B/yr compared business-as-usual power system build out (Langevin et al 2023). In 2022, the California Energy Commission (CEC)'s Next EPIC Challenge: Reimagining Affordable Mixed-Use Development in a Carbon-Constrained Future, awarded twelve teams throughout the state to propose a design for a real, affordable mixed-use development that provides radical load shifting, on-site power generation, and resilience capabilities. Continuing into a build phase this year, the implicit suggestion of the challenge is that multifamily buildings are a critical sector for serving the need for grid stability, and a focus on affordable housing in particular stands to benefit low-income communities. However, given the costs of distributed energy infrastructure and the challenges of constructing and retrofitting affordable housing, it is far from clear whether this is the right ideal to aim for. In today's new construction market, we are already seeing this uncertainty play out in real time as non-profit developers navigate battery requirements in the 2022 California Energy Code and California's third iteration of net energy metering (NEM) policy takes effect without the tools to determine the economics of these regulations for housing providers. In responding to the CEC challenge as a design-phase grant awardee, our team focused on several key research questions that could help address these immediate market challenges and chart a path toward an equitable energy transition:

1. What is the most cost-optimized solution for achieving full load flexibility (as defined by the design requirement to eliminate 4-9pm peak usage, daily) for a typical mid-rise affordable housing project?
2. What are the economic and resilience benefits of grid-interactive design for the property owners and residents, and do these priorities conflict with grid priorities?
3. Finally, what are the barriers to widespread adoption?

Method

To explore these questions our team completed a design for Roosevelt Village, a project under development, in partnership with the developer, contractor, and full design team. The case study project, a 6-story, 71,000 ft^2, wood-framed podium building on a 0.42-acre site near downtown San Jose, California, typifies the housing that is most common and cost-effective to finance and construct today in urban areas, where the highest concentration of affordable housing exists.

We used multiple simulation tools in tandem to determine a cost-optimized combination of investments that would also be realistic for a non-profit owner to operate and maintain and would not compromise or control residents' daily routines. We compared performance outcomes from a suite of potential energy efficiency, energy recovery, and load management strategies in EnergyPlus, including multiple heating, ventilation, and air-conditioning (HVAC) and hot water systems options, and then used Xendee, a distributed energy resources (DER) optimization software, to analyze the economics of deploying combinations of load-reduction measures compared to on-site generation, thermal storage and battery storage. Up-front cost were achieved in partnership with the general contractor on the project, at a schematic-design level of development, and refined based on coincident projects going out to bid.

This analysis was accompanied by a multi-stage engagement process with property management, on-site services staff, and residents from a similar property to define resilience goals for the property and critical loads for back-up power. A technical advisory committee of non-profit developers, researchers, engineers, utility representatives and product vendors also assisted the study.

Figure 1. Rendering of Roosevelt Village, 995 East Santa Clara Ave, San Jose

Results

Baseline Energy Use

A baseline energy model for Roosevelt Village was constructed using EnergyPlus. This baseline meets the specifications of a standard-practice project for this area, which is all-electric (local requirement), uses ENERGY STAR appliances and LED lighting, and heat pump water heating. The baseline energy use intensity (EUI) was estimated to be a high-performing 23 kBtu/ft^2. As shown below in Figure 2, almost half of the electricity (48%) is consumed by tenant meters, with a significant portion (75%) of this share going to the refrigerator, range, television, lights and plug loads.

The next significant end-use for the building is the domestic hot water at 20%, and other aggregated, non-residential house loads at about 25%, of which lighting accounts for roughly half. The dedicated outdoor air system (DOAS) accounts for 40% of the non-residential category or about 9% of the total building's annual electricity consumption. Space heating and cooling are relatively minor (16% of the building's total energy use) but significant percentages of aggregated house (25%) and resident loads (20%).

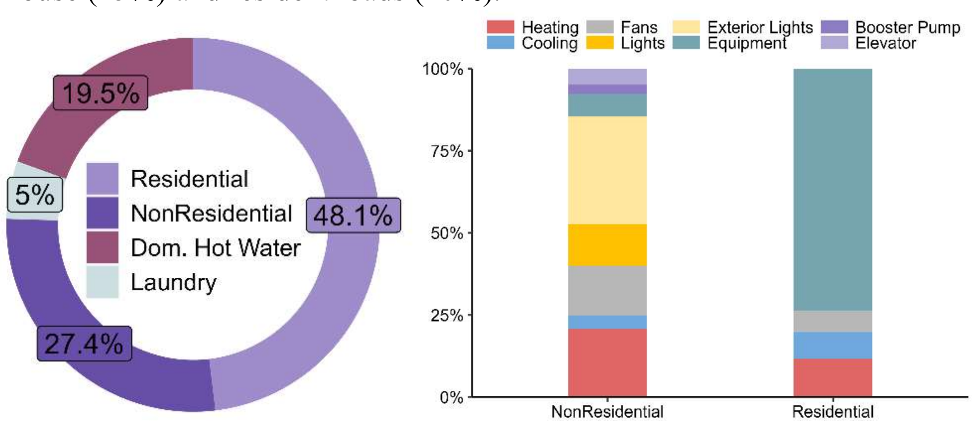

Figure 2. Baseline energy demand by end use

Daily power demand profiles for the building show that residential loads and hot water dominate the daily 4-9pm period except on peak cooling days, when cooling is a significant power demand during the late afternoon.

These profiles were derived from measured data from existing multifamily buildings with similar resident characteristics to our case study, including daily and hourly electricity consumption datasets at the building or apartment level from multiple sites. Because there is limited hourly measured data available, we supplemented the measured data with the Pacific Northwest National Lab (PNNL) multifamily reference whole building energy model. The combination of these data informed the typical peak electrical load and diversity factor across apartments by hour of day. A detailed discussion of the modelling process and diversity assumptions can be found in a project specific *Energy and Emissions Report* (Duarte et al., 2023).

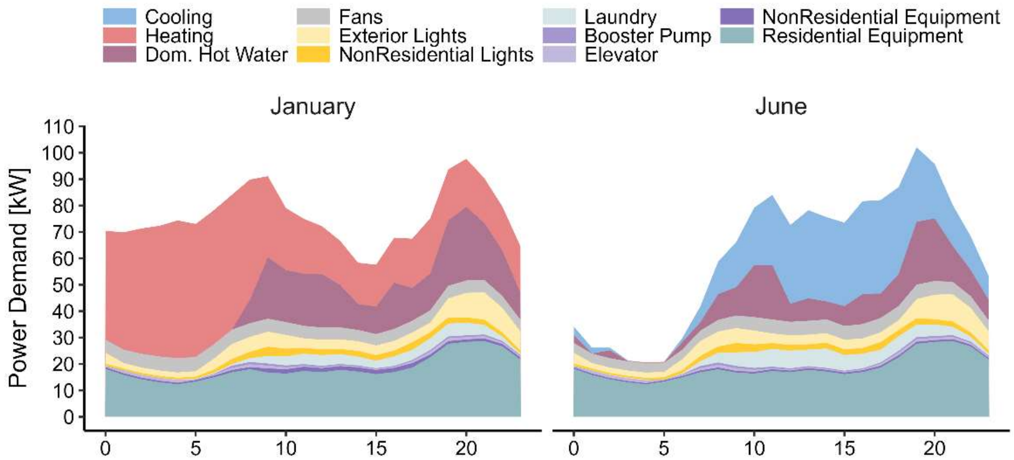

Figure 3. Baseline daily power demand profiles at near peak heating (left) and cooling (right) conditions

Optimizing load reduction, load management and DER measures

We evaluated a range of emerging and underutilized technologies and control strategies that could reduce the building EUI further and shift as much load as possible outside of 4-9pm, aiming to cover the remainder with on-site PV and batteries. After some measures were eliminated due to insufficient simple payback and avoided battery cost, final packages were co-optimized for life-cycle cost and emissions in a DER optimization software, Xendee, , alongside thermal storage, battery storage, and on-site generation scenarios.

Because heating and cooling loads are relatively small and the standard building envelope is already efficient, few envelope and thermal storage strategies targeting these loads are worthwhile in terms of reducing life-cycle cost or emissions. Adding 1” continuous insulation and exterior metal sun shades, which might be expected selections, have negligible impact on demand and very high embodied emissions and cost. A hydronic heating and cooling system, with abundant thermal storage, was successful at reducing heating and cooling demand during 4-9pm to almost nothing, but barely surpassed standard heat pumps in life-cycle emissions reductions and had such a substantial cost premium in addition to market and operational barriers, thus re-tooling standard practice to support this technology made little sense.

Instead, our final package included simple measures like slimline packaged heat pumps, increased air tightness, induction cooking and ceiling fans. Adding heat recovery to the central

DOAS was also beneficial; although an expensive measure, the ability to eliminate compressor-based tempering and reduce load during peak winter nighttime hours proved cost-effective and advantageous in terms of operational resilience. We also included a bypass on the heat recovery to admit cooler outside air during summer when economizing can help offset compressor-based cooling.

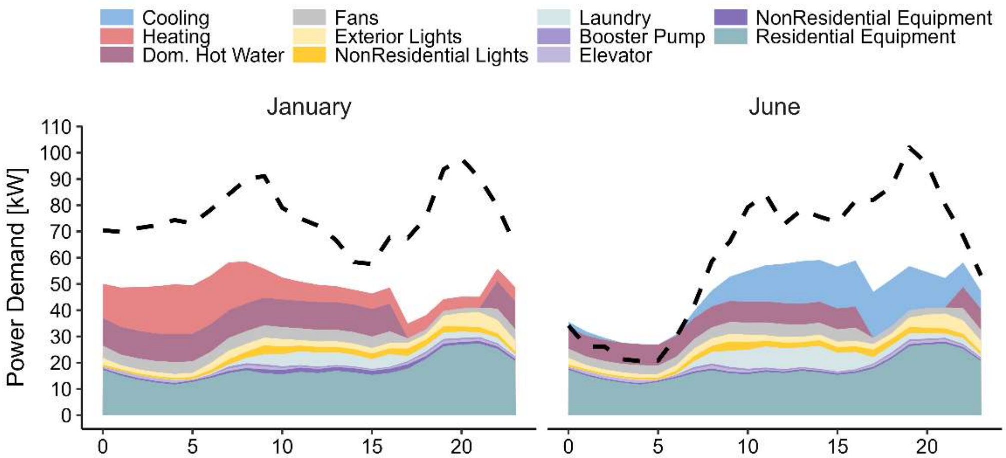

Figure 4. Daily power demand profiles for near peak heating (left) and cooling (right) conditions with adopted measures. The ability to eliminate the cooling load that remains during 4-9pm on the hottest days of the year was the chief benefit of the hydronic heating/cooling measure, which was abandoned.

Fully leveraging the thermal storage potential of the central water heater is the single most impactful measure, eliminating one third of the 4-9pm peak at a modest incremental cost. Our design included a central SanCO2 heat pump bank that had 1/3 more storage and 20% more capacity than a standard design. Several other load management strategies (see Table 1), including the ability to modulate ventilation rates, combined to offer a worthwhile 14% of additional peak load shift. Overall, our optimization resulted in a combination of strategies that left only 38% of the annual consumption during 4-9pm remaining for PV and battery systems to cover.

After assessing a number of PV emerging technologies (including façade-integrated PV, and bifacial panels), racking systems and orientations, our modeling exercise led us to max out rooftop PV with a 171 kW monofacial array elevated on structural steel, with a 0-degree tilt and ground coverage ratio of 0.98 oriented with long axis in the SW-NE direction. Based on cost, constructability and dramatic increase in annual energy production offered by the elevated canopy, this solution emerged as the lowest lifecycle cost once accounting for avoided battery capacity needed to fully shift grid consumption out of the daily 4-9pm window every day of the year. A 268 kWh battery was identified as the optimal size to meet the daily 4-9pm requirement when paired with the elevated 171kW rooftop PV canopy. For comparison, an unelevated 130 kW rooftop array (i.e. a more typical rooftop PV installation) would require a 593 kWh battery to achieve the same daily shifting outcome.

To achieve the daily offset of residential energy consumption 4-9pm, a virtual net energy meter (VNEM) configuration was decided upon, principally because it enables the residents to share in the utility bill savings from the on-site generation systems and it grandfathers in a NEM

2.0 rate which makes the project economics much more favorable (see Lifecycle Costs section below). Microgrid infrastructure allowing the building to island from the grid was a design requirement, and since our final battery and PV system size would be oversized to provide backup power just to the house meter, and because the building would serve a senior population for which some critical loads were identified as in-apartment loads, we designed switchgear and wiring to allow backup power to serve each apartment in addition to the common spaces.

Table 1. Final combination of measures and impact on peak reduction and up-front cost

Strategy	Portion of Annual 4-9pm Load Served	Approximate Incremental Cost*
Energy Efficiency	10%	$550,000
Thermal Storage (domestic hot water)	32%	$50,000
Peak Load Management Dynamic Ventilation Light dimming Ohm Connect[1] Laundry incentives[1]	14%	~$0
Solar PV array, Battery Storage including VNEM infrastructure	38%	$1,500,000
Microgrid infrastructure	NA, enables islanding	$500,000
Total Incremental Cost		~$2,600,000
Total Construction Cost		**~$50,000,000**

* Costs are approximate and demonstrative

Life-cycle cost and emissions

As shown in Table 1, the total incremental cost for a fully grid-interactive housing project came to $2.6 million (without incentives) -- or roughly 5% of the total construction cost -- 80% (or $2 million) of which is related to distributed energy resources and microgrid design.

We calculated life-cycle cost over 30 years with state and federal incentives applied, under both a NEM2.0 tariff and a NEM3 Virtual Net Billing tariff. Critically, projects funded by California's Solar on Multifamily Affordable Housing Program (SOMAH) are virtually net metered and grandfathered into NEM2.0 tariffs, which are essential in controlling the life-cycle costs of the grid-interactive design by maximizing the financial benefit of exports.

The 30-year net present cost of our proposed design over a code-minimum standard building without grid response is $1.4 million above a code-minimum building ($1.0M after incentives) as shown in Figure 5. This LCC increase is despite 88% total utility bill savings (shared between owner and tenants) resulting from optimized investments in DER and non-DER strategies. Although cheaper than it would have been without efficiency investments, the overall bill savings is unfortunately not enough to make up for the large incremental cost of the increased PV and battery systems compared to current practice.

[1] These strategies assumed voluntary behavioral energy reduction from residents based on incentives (eg. cheaper laundry prices outside of the 4-9pm window). It was challenging to find good data on the impact this might have, so for analysis purposes their effect was assumed to be minimal.

The percent of the bill savings that is allocated to tenant meters vs the house meter is discretionary, but must be over 50% under SOMAH, to unlock NEM2.0 tariffs. We found a balance point whereby a 63% resident allocation would zero out annual house utility bills while reducing resident bills by 90%. We looked at life-cycle costs with and without CARE rates (California's alternate rates for low-income households), which turned out to have a negligible impact.

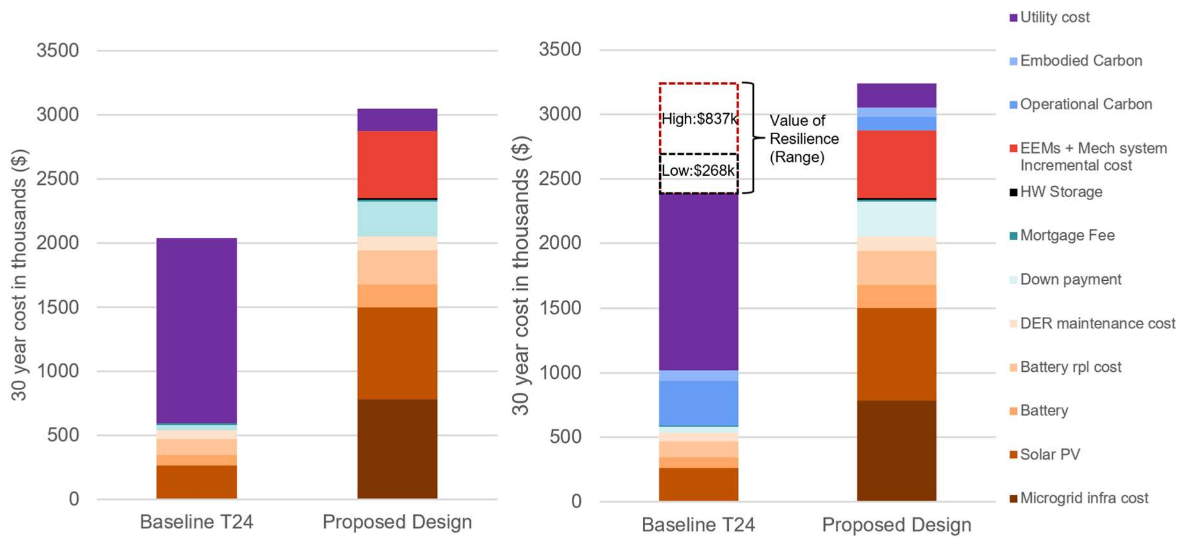

Figure 5. 30-year life-cycle cost compared to code-minimum baselines. Assumes NEM 2.0 tariffs for SOMAH/VNEM project with currently available state and federal incentives. Chart on the right includes an estimate of the value of resilience and carbon reduction with EPA proposed Social Cost of Carbon at $190/ton

Social cost of carbon and value of resilience

A life-cycle cost based on operating cost savings alone ignores the societal benefit of distributed energy and enhanced resilience. To re-balance this equation, we assigned a social cost of carbon to the embodied (one-time benefit in the year of construction) and operational (over the 30-yr analysis period) carbon savings of our design, and looked at ways to assign a monetary value to the resilience benefit that is obvious but hard to quantify. Figure 5 shows the contributions of these factors to the life-cycle cost, essentially arriving at cost parity with a code-minimum building. We used the EPA value of $190/ton for the social cost of carbon, which increases to $310/ton by 2050 (2020 $) (EPA 2023). To place a value on resilience, we drew from two recently published methodologies (Sullivan, Schellenberg, and Blundell 2015; Lewis 2021), which suggested a 30-yr net present value of approximately $268k - $837k for this site.

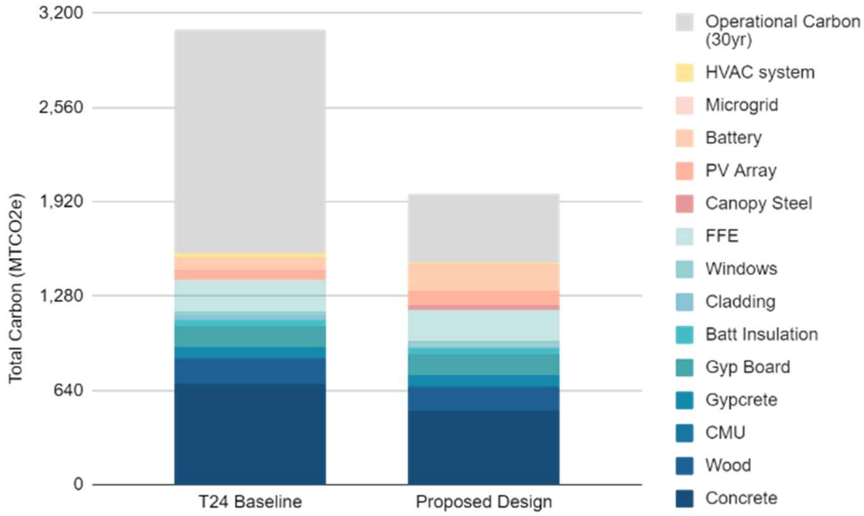

Figure 6. Lifecycle carbon comparison (embodied and operational over 30 years) of baseline and proposed design

The proposed design achieved a nearly 40% reduction of greenhouse gas emissions over 30 years, which includes a cradle-to-gate estimate of embodied emissions reduction using Tally Our proposed HVAC and DHW design is responsible for 30% of the total emissions reduction, primarily due to the use of thermal storage to shift loads to lower carbon hours with negligible increase in embodied emissions. It should be noted that there is very little information and tools available to accurately account for embodied emissions of HVAC and DER equipment.

Resilience

Outage scenarios and priority loads. Based on conversations with staff and existing residents, the team developed outage scenarios and then summarized essential and priority services for each scenario. Although close to downtown with good connectivity and grid reliability, short-term outages of up to several hours are relatively common (1-5 per year). In addition, Roosevelt Village would serve formerly homeless seniors, who would tangibly benefit from resilience to power failure. Longer 1-3 day outages are rarer but possible during major storms or earthquakes, and in these scenarios having backup power is even more critical.

When we asked residents of a similar, nearby property what they would prioritize in an outage, the single load that mattered most to them was refrigeration in their homes, in order to preserve personal food items and medications. This was closely followed by a concern for general safety in communal areas, in particular building access, corridor lighting, and elevator operation. Hot water also ranked highly as a preferred function to maintain during an outage, while HVAC and apartment lighting were ranked less important. Staff were most concerned about building access and security systems, basic office functions, and communication with staff during an emergency.

Coverage of priority loads during Outages. We analyzed what percent of priority loads could be covered for 24- and 72-hour outage scenarios throughout a typical year, along with the acceptability of indoor conditions. We also looked at battery sizing required to run "Tier 1" priority loads indefinitely, which was a requirement of the CEC Challenge.

When the battery is sized for the 4-9pm load shift, a 268 kWh central battery is needed. This capacity is roughly equivalent to one day of "Tier 1" loads (265 kWh) which include one elevator, building security and access systems, cold water booster pump and hot water recirculation pump, common area emergency lighting, and the central DOAS, in addition to residential refrigerators, ceiling fan/light, and one usb plug in each apartment. This means that the basic functions of the home – refrigeration, filtered fresh air, power for devices, comfort control, and cold and hot water (until the hot water storage is exhausted), in addition to basic common area safety, can be supported indefinitely by on-site resources for the vast majority of the year, which would be a radical level of resilience for any multifamily building, particularly one providing affordable housing.

To place in-unit loads on back-up power, our electrical design includes a bypass relay at each apartment electrical panel, which switches the power feed from the residential meter to the house meter when the grid goes down.

With residential HVAC excluded from priority loads, we ran an indoor temperature model which predicts comfortable conditions up to 72 hours during an outage in peak winter and summer conditions, with ceiling fans, heat recovery ventilation, and operable windows being essential components. The common room HVAC system was assigned to Tier 1 so it could serve as a heat stress refuge for residents if a multi-day outage occurs during extreme conditions.

Table 2 summarizes the battery sizing necessary to support Tier 1 and Tier 2 loads for different durations. 'Tier 2" loads include additional functionality in offices and amenity areas and the central domestic hot water heat pumps. Tier 2 loads would come online or be shed according to a specified threshold state of charge for the battery.

Table 2. Battery sizes necessary to meet peak load shifting and backup power scenarios

Battery Size	Daily 4-9pm Res Loads	Indefinite Tier 1 loads	24 hr outage (Tier 1&2)	72 hr Outage (Tier 1&2
Full Peak shift (268 kWh)	100%	99%	90%	73%
Medium (400 kWh)	100%	99.7%	98%	80%
Large (600 kWh)	100%	99.9%	100%	90%
Huge (1,300 kWh)	100%	100%	100%	100%

Battery sizes assume an elevated canopy PV array and the proposed design efficiency measures

As shown in Table 2, covering the 'worst case' annual conditions for backup power (which are largely driven by poor PV generation) drives up costs considerably – eg. the last 1% of Tier 1 loads coverage takes a battery that is almost 5x the size. An innovative approach to this problem that we identified is to buy an all-electric truck as a building maintenance vehicle with a bi-directional charger. The truck can drive elsewhere to charge during an outage and then supply another 131 kWh of battery capacity to the building during an outage, essentially eliminating any gaps in indefinite Tier 1 and 24-hr outage (Tier 1 and 2) coverage.

Design Recipe

One of the primary goals of this work was to produce a set of generalizable design recommendations for mid-rise affordable housing in California's major urban centers (eg. Bay

Area and Los Angeles) that achieve a level of grid-interactivity and resilience that benefits the community and contributes to grid decarbonization. The key ingredients, or principles, of the recommended design recipe are below.

1. **Domestic hot water storage and load shifting.** One of the key learnings from this work is that sizing DHW storage and enabling controls to fully shift heat pump water heater operation outside of the daily peak window (4-9pm), and into the low grid emissions solar generation window, is one of the most cost-effective and impactful strategies, but is not currently common practice. Even absent the futuristic design requirements, most standard central DHW designs contain sufficient storage to substantially shift central heat pump water heater operation and this represents a significant opportunity for midrise affordable housing. An ideal control strategy would incorporate time-of-use rates and a real-time carbon emissions signal and optimize heat pump operation to minimize both costs and carbon. A simpler control strategy would raise the DHW water temperature setpoint during the day to naturally drive consumption into that window while still ensuring sufficient storage to meet DHW demand – the tradeoffs with this strategy would be mostly during nighttime hours when prices are low, but emissions may be high or during hot summer afternoons when additional daytime load could further stress the grid. An example DHW shifting outcome that is co-optimized for cost (based on a TOU rate) and emissions for Roosevelt Village is shown below:

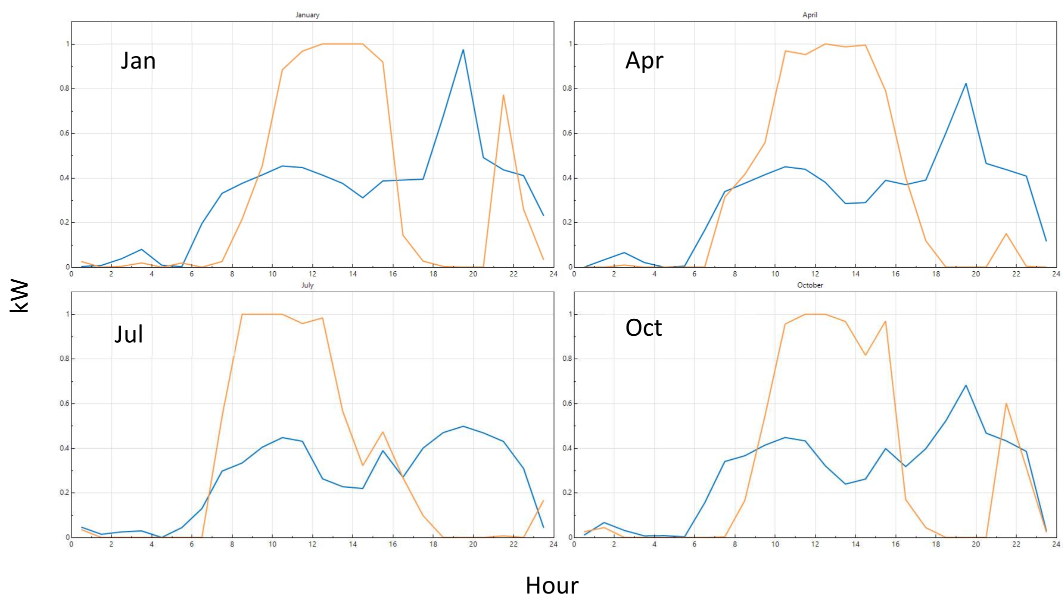

Figure 7: Normalized average heat pump water heater daily profiles by season with load shifting (orange) and without (blue)

2. **Beyond code energy efficiency.** Title24 continues to advance the boundaries of new construction building performance, resulting in highly efficient buildings even at the minimum compliance level. However, designing for radical grid-interactivity changes the cost effectiveness calculus such that additional efficiency measures may become worthwhile**, s**pecifically measures that produce savings during the daily peak window (4-9pm), reduce priority loads, or reduce power consumption during extreme weather conditions. Reducing

energy demand during these periods has a direct impact on battery system sizing, thereby increasing the value of the measures. The specific set of measures that fall into this category are likely to vary somewhat by project depending on the unit mix and density, height and location, however some measures could be assumed beneficial for all projects, such as ceiling fans, induction cooking and 1.5gpm showerheads. Other measures, such as energy recovery ventilation and triple-pane windows, could be verified by a simple cost payback analysis during design. Finally, it's unlikely that continuous insulation for wood-framed walls makes up for its high cost and high embodied emissions, at least until emerging carbon-absorbing insulated cladding products become more available. Similarly, other emerging technologies such as phase-change materials integrated into wall systems, or dynamic glazing, would have to be offered at **much** lower-than-current premiums to be considered.

3. **Max out PV generation.** This may sound like counter-intuitive advice given the current California landscape of duck curves and net energy metering roll backs, but PV generation is critical to achieving the design requirements (especially daily shifting out of 4-9pm and resilience goals) and mid-rise buildings are likely to be constrained with rooftop area sufficient to support the cost-optimal PV system size. There is a design trade-off between PV size and energy storage system size, but given the relative costs of PV panels and batteries, maximizing PV generation and minimizing battery size will almost certainly be the cheapest option if shifting residential loads out of the evening peak is the goal. Maximizing PV generation also provides longer resilience during power outages. At Roosevelt Village, it was found to be more cost effective on a lifecycle cost basis to build a steel rooftop canopy to expand the rooftop system size by 30%, essentially raising the $/kW cost 5x, rather than sizing up the battery. Where available, in addition to rooftop area, opportunities for ground mount systems (eg. carports) or façade-integrated PV should be explored. Optimal orientation should also be explored – west facing PV systems may provide more power during the peak window, but generate less energy overall. At a site where generation is not constrained, at least some west-facing PV may be preferable, but at a site with constrained PV area, maximizing the annual energy output is likely to be the preferred option.
4. **Heating and cooling don't need thermal storage.** The combination of beyond code efficiency measures and mild climates shrink heating and cooling loads significantly. Additionally, winter heating loads diminish during the daily peak window as internal gains typically ramp up in the evening. And the peak conditions that drive battery sizing are not likely to be coincident with high heating or cooling loads – that is, battery size is mostly driven by days when there is poor PV generation (i.e. cloudy days), and cloudy days are not typically the coldest or hottest days. Finally, there is a large up-front cost difference between in-apartment packaged heat pumps and a 4-pipe central hydronic system with thermal energy storage – even if that same system can provide DHW and thermal storage for load shifting heating and cooling loads. Thus, the recommendation is to utilize efficient in-apartment packaged equipment and size PV and battery systems to serve the HVAC loads during the daily peak window.
5. **Utilize central shared systems where possible**. Load diversity across apartments and with any commercial space in the building allows central systems (eg. PV, battery, DHW) to be smaller and **typically** cheaper than the sum of per-apartment systems required to achieve the same objectives, with the exception of HVAC as described above. This is applicable to standard business-as-usual buildings too, particularly domestic hot water (DHW) systems.

However, incorporating the daily requirements for the building to satisfy all residential loads during peak hours extends this consideration to include photovoltaic (PV) and battery systems as well.

6. **Size battery for remaining peak loads plus any buffer.** For sites in urban areas, where outages are relatively less common and resilience is less valuable, the battery can be sized to meet the remaining loads during the daily peak window (after load shifting and shedding has occurred). If backup power is desired in apartments, sizing the battery to cover worst-case power outage conditions is likely to drive up the required battery size considerably, and there may be other creative solutions such as bi-directional charging for electric maintenance vehicles that can help close those gaps. For sites with less reliable grid connections, a decision must be made on whether or not backup power will be provided to the apartments, common areas, or both. Under current regulations that require individual apartment electric meters, providing in-unit backup power requires considerably more electricity infrastructure (additional wiring to each apartment, transfer switches, etc…) and costs will need to be weighed against the benefit of enhanced resiliency for residents. Relatedly however, if the site has a battery and PV system sized to shift loads out of the peak window every day, it will likely have enough capacity to offer some lever of meaningful resilience at the apartment level, in addition to critical common area loads.

Barriers to Widespread Adoption and Policy Implications

In order to scale the proposed design recipe, a number of barriers would need to be overcome.

Costs

The first and perhaps most important barrier to widespread adoption is the up-front cost premium, particularly of infrastructure components. As shown above in Figure 5, the incremental first cost of the proposed design at Roosevelt Village was $2.6M; while this seems like a modest incremental cost on a $50 million project, it is far above what would be acceptable in the current affordable housing finance environment. Additionally, the 30-yr lifecycle costs of the proposed design were $1M higher than the baseline Title 24 building under NEM 2.0 and $1.5M higher under NEM 3/VNBT, indicating that the societal value of adding distributed energy infrastructure to urban housing is a key discussion, and most likely will not apply equally to all projects. Subsequent subsections discuss various ways the proposed recipe might become more competitive with business-as-usual.

Metering Regulation

The California Public Utility Commissions' Electric Rule 18 requires that new multifamily buildings have separate electricity meters to each apartment, effectively outlawing master metered buildings. There are numerous reasons why this rule was originally passed including tenant protections from landlord upcharges on utility rates and aligning economic incentives for tenants to reduce energy consumption. However, a master metered building would considerably simplify the electric infrastructure required to meet the grid-interactive and resilience outcomes intended in the design requirements of the CEC Challenge. Given that over 38% of the incremental first costs for Roosevelt Village are related to electric infrastructure to support virtual net metering and apartment-level backup power, a master metered configuration would represent considerable savings, enough to considerably close the lifecycle cost gap with a business-as-usual Title24 building under NEM 2.0 (see Figure 5, there would still be a gap under NEM 3.0). Figure 8 below shows electrical design schematics for a master meter configuration and an individual apartment meter configuration with virtual net metering. Both designs achieve the same goals in terms of offsetting residential power during the daily peak window, providing backup power to the apartments in addition to the house meter, sharing the utility bill benefits of the central PV and storage systems with residents, and an economic incentive for residents to reduce energy consumption (with proper sub-metering in the master metered case). The master meter building has the additional benefits that under NEM 3/VNBT, it would be able to self-consume some of the on-site PV generation which would effectively be valued at the full retail rate, whereas the VNEM configuration would see reduced value for all of its PV generation, as it would only be exports.

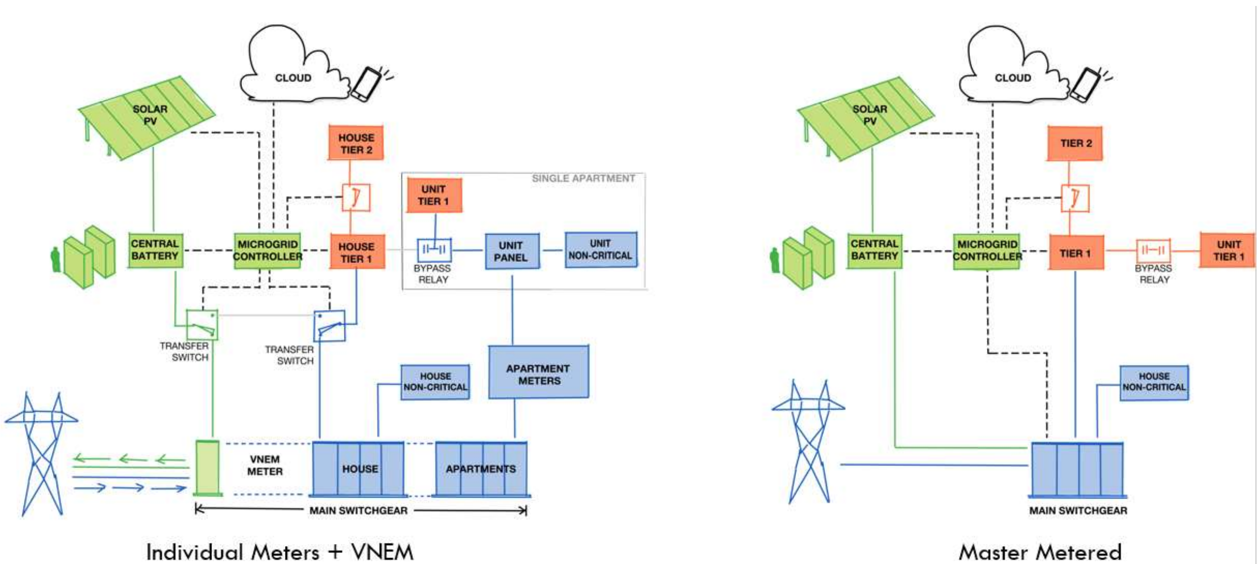

Figure 8: Left: Individual apartment electricity meter schematic with virtual net metering, and in-apartment backup power (currently allowable in CA); Right: Master metered electrical schematic to provide daily peak window power to apartments and in-apartment backup power (currently this configuration is not allowable in CA)

While there were some very good reasons to outlaw master metered new construction when Electric Rule 18 was passed, it may be time to reconsider in light of technology advancements that can allow for better submetering (eg. smart panels, wifi-enabled energy monitors), better transparency for tenants about their utility bills, and the desire for buildings to play a critical role in decarbonizing the electric grid.

Electricity Rates and Market Structures

The three primary avenues for a building with our proposed design recipe to recoup the incremental first-costs are 1) price arbitrage with time-varying utility rates; 2) compensation through net metering; 3) demand response and wholesale market opportunities; The design recipe described above, and any economic analysis of a building attempting to utilize a similar design, is going to be highly sensitive to these three variables.

Time-Varying Rates. Today most new affordable multifamily construction in CA will be on a time-of-use rate, and with PV and storage systems, a time-of-use rate is often required. These rates provide some economic incentive/compensation for completely avoiding peak windows, and while the price arbitrage opportunity between peak and off-peak times has grown in recent years, it is still relatively small – on the order of $0.09/kWh. Applying this arbitrage opportunity to just the DHW system at Roosvelt Village, we could expect a $2,246/yr utility bill savings. However, spread across 74 apartments this only amounts to $28/yr per apartment, perhaps not enough to sufficiently incentivize owners or designers to wade into the complexity of setting up the controls to achieve these outcomes – it also does not likely produce enough value alone to justify the additional up-front costs in DHW storage capacity needed to completely avoid the daily peak windows on every day of the year.

Table 3. Domestic Hot Water Load Shifting and TOU Value

Annual DHW energy consumption during peak window (4-9pm) – no shifting (kWh)	Annual DHW energy consumption during peak window with shifting (kWh)	Electricity TOU peak v. off-peak price delta ($/kWh)	Annual savings from shifting ($/yr)
23,638	0	$0.095	$2,246

An alternative to time-of-use rates that may provide more value to customers and better aligned value with the grid operator could be a real-time price of electricity, inclusive of grid infrastructure costs, carbon emissions, and wholesale energy costs. A real-time rate, similar to the CPUC's Avoided Cost Calculator (CPUC 2022), would more directly address the type of grid-interactivity that the proposed design is trying to achieve, however, it would also further complicate building controls in being able to respond to the rate, though it could also simply be scheduled on a daily basis to shift out of the same 4-9pm peak window.

Net Energy Metering. The ongoing evolution of net metering policies in California has dramatic implications for the cost-effectiveness of the proposed design recipe. As shown above, under a NEM 3 Virtual Net Billing Tarriff, utility bills at Roosevelt Village are estimated to increase by over 3x compared to a NEM 2.0 scenario. Under NEM 2.0, solar or battery exports during the peak window are worth somewhere around $0.4/kWh, over 4x the arbitrage opportunity described above. While VNEM systems on affordable housing will be grandfathered into to NEM 2 for nine more years, the eventual transition to NEM 3 will erode a lot of the savings our design recipe and create a need for new revenue streams to help fill the gap.

Demand Response and Wholesale Market Opportunities. One such revenue stream that may continue to grow is through participation in demand response or wholesale energy markets. For Roosevelt Village, the project team explored participation in these programs, but currently almost all wholesale markets in CA don't allow exports, only energy reductions. And since the building was not going to use grid power during the peak window every day, there would be no baseline energy use from which a reduction could be measured. Related to an earlier point, this is another disadvantage of the VNEM configuration – battery storage discharge won't show a load reduction on the grid because it is exported through the VNEM meter; another area where a master-metered configuration would be well positioned to respond. One wholesale program, the

Emergency Load Reduction Program, does compensate buildings for exports at a rate of $2/kWh and calls up to 60 events per year, each up to 4 hours.

Individual apartments are also eligible to participate in demand response programs. While the solar, battery, and DHW systems are central, residents could utilize their thermostats, refrigerators, and other plug loads to participate. In the individually metered scenario, these benefits wouldn't help recoup the up-front costs, but would benefit residents.

Energy Code Compliance

If appropriate financial incentives are lacking to justify the increased up-front costs, another avenue to get more grid-interactivity out of affordable housing would be to require it through Title 24. There are currently prescriptive requirements for solar PV and battery storage, however designers and consultants lack the tools to perform optimization studies to identify the most valuable control algorithms or sizing to pursue. Most importantly, thermal storage of central DHW can not be leveraged in the current compliance software, pushing developers to invest in batteries or high-cost efficiency measures to meet compliance.

Given the Barriers, What Should We Do?

1. **Focus on hot water storage**. Programs, manufacturers and code development should encourage thermal storage over battery storage and make it easier for designers and operators to fully leverage domestic hot water through analysis and control platforms that make load shifting simple and easy.
2. **Let resilience need drive battery deployment**. Where there is limited risk of power failure, which is true in many urban centers, or based on the resident population, the cost of the additional infrastructure may prove that on-site battery storage is not suitable, especially when a substantial amount of grid-interactivity can be achieved without a battery as discussed above. Where resilience IS a priority, programs are needed to incentivize developers to size battery and PV for grid-interactivity and resilience, considering the needs of the property or residents for in-unit backup power. This increases the cost but maximizes the societal benefit.
3. **Drive product development to meet the market**. The focus on affordable housing as the frontier for a clean energy transition and grid decarbonization is at odds with the typical focus of technology and product developers in other markets, especially high-end single-family early adopters. We need more recognition of the market for products that serve this sector, including everything from induction ranges and packaged heat pumps to software and third-party entities that can deliver microgrid solutions.
4. **Argue for master metering**. In the end, achieving a cost-effective grid-responsive building is challenging without master-metering. The CPUC should reconsider this policy if multi-tenant properties are going to be part of the energy transition and cost-effectively get a resilience benefit from on-site energy storage and generation resources.

While barriers to radical grid-interactivity and resilience are being worked on, utilize code compliant PV+battery systems in affordable housing to minimize costs and emissions, and provide meaningful resilience to residents.

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