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Transforming New Multifamily Construction to Zero: Strategies for Implementing Energy Targets and Design Pathways

Preprint

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Transforming New Multifamily Construction to Zero: Strategies for Implementing Energy Targets and Design Pathways

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ABSTRACT

Creating zero energy (ZE) mid- to high-rise multifamily buildings represent significant challenges in the design world. Tenants often take responsibility for some of the utilities and are responsible for consumption of some of the largest end uses: hot water and plug loads. Furthermore, designers can experience risk in creating new sets of details and recommending new strategies to reach aggressive EUI targets. To assist in a more streamlined and successful design approach to ZE multifamily buildings, five major professional societies and experts from the multifamily space created a Zero Energy Advanced Energy Design Guide (AEDG) for multifamily buildings based on data driven results coupled with actual design experiences and case studies. Pathways to achieve ZE design were established including whole building energy use intensity targets coupled with details on how to achieve success in implementing individual efficiency measures. The guidance strives to overcome design barriers and this paper provides an overview of the recommended process to achieve ZE or ZE-ready status, along with details on selecting energy targets, and strategy pathways to achieve the targets.

Background

Commercial buildings have greatly improved their performance over the past few decades due to many advancements in high performance heating, ventilating, and air-conditioning (HVAC) systems; lighting systems; water heating approaches; and electrical equipment combined with tighter, better-insulated thermal envelopes with advanced glazing. With increasing market demand and a drive from state and local policy in locations like California[1] to continually reduce building energy use intensity (EUI), evaluating energy efficiency has been a critical component of the design process – one that needs to be considered in every design decision in order to achieve ultra-low EUI targets.

Zero energy (ZE) and zero energy ready (ZER) buildings are extremely energy-efficient buildings that have the capacity or potential to produce as much energy as they consume by adding on-site renewable energy sources. The U.S. Department of Energy (DOE) published a common ZE definition in 2015 (DOE 2015): "An energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable

[1] For example, California adopted ZE targets for 50% of the floor area of existing state-owned buildings by 2025 and for all new or renovated state buildings beginning design after 2025 (SAM 2017). California has also set a target of making all new commercial buildings ZE by 2030 (CPUC 2011). Several other states are moving forward along the same lines.

exported energy." This definition applies to individual buildings, as well as campuses, communities, portfolios, or any other specified boundary.

Achieving ZE or ZER (ZE/R) status at scale has been examined and validated. Griffith et al. (2006, 2007, 2008) examined the entire commercial sector via a comprehensive energy modeling analysis to determine which building types could achieve ZE/R and what levels of energy efficiency were needed to achieve that goal. The study found that the concept was technically feasible for significant portions of the commercial sector.

As ZE/R goals have evolved and grown, the published ASHRAE Advanced Energy Design Guides (AEDGs) have evolved as well (ASHRAE 2020). This guidebook series has had more than 678,000 copies in circulation as of June 2020. The efficiency targets and recommendations in the guides are based on extensive energy simulation, input from industry experts, and comparisons with case study buildings. They offer comprehensive recommendations on how to achieve ultra-low EUI targets that go beyond typical new construction and major retrofit processes and techniques. The AEDG series began in 2004 providing guidance for six building types to achieve 30% energy savings compared to ASHRAE Standard 90.1-1999. In 2011, the guides shift to achieve 50% energy savings from ASHRAE Standard 90.1-2004 and applied to five building types. In 2018, ASHRAE released its first ZE AEDG focused on K-12 Schools (ASHRAE 2018), and in 2019 a second ZE AEDG was released focused on small to medium size office buildings (ASHRAE 2019 a). The latest ZE AEDG will be published in fall 2020 and is focused on multifamily buildings larger than 3 stories.

The main focus of the AEDGs has always been to provide design guidance based on simulation and goals that are achievable using widely available technologies. With advances in technology, clear design guidance, and sharp reductions in renewable energy costs, integrated design solutions can more easily and cost-effectively produce ultra-low energy targets. These trends are corroborated by a dramatic increase in the number of documented ZE buildings (NBI 2018).

A growing category for ZE/R buildings is the multifamily sector. Multifamily buildings often merge aspects of residential and commercial buildings and represent a diverse set of business models that include high-rise, low-rise, market rate, affordable, and assisted living, amongst others. The work conducted for this ZE AEDG focused on understanding key components to multifamily energy consumption and providing recommendations that can serve different multifamily business models. Energy model simulations helped inform the guide recommendations.

The Process of Creating Design Guidance

Many resources provide information on the idea of ZE/R goals and how they are taking hold in the marketplace (Liu et al. 2017; Torcellini et al. 2016). The ZE AEDGs go beyond past resources by providing comprehensive recommendations and achievable EUI targets by climate zone for particular building types. The ZE AEDG EUI targets also serve as an operational goal as success in meeting the goal is measured after a minimum of one year of energy performance.

The AEDG has been well-vetted by industry experts and leaders. Notably, a steering committee made up of members from ASHRAE, IES, USGBC, AIA, and DOE created the scope for the multifamily ZE AEDG. The steering committee formed a special project committee consisting of technical experts in HVAC, lighting, plug loads, envelope, and architecture, with a strong emphasis on experience delivering or operating multifamily buildings. In addition, the project committee convened an external group of subject matter experts to provide feedback on the project approach, content, and recommended ZE/R strategies specific to multifamily buildings. This committee also offered insights into the reality of industry practices and norms for consideration as well as consulting to the project committee through peer reviews and answering directed questions. Case studies with measured and verified energy data were also collected and examined to support the recommended energy efficiency strategies and operational EUIs.

Leveraging energy modeling expertise from the National Renewable Energy Laboratory, the committee conducted comprehensive analyses on various energy efficiency strategies for multifamily buildings, and developed consumption EUIs that could be met with on-site renewable resources in various climate zones. Through simulation, the team was able to evaluate many different scenarios and identify optimal parameters of design strategies and technologies to achieve ZE/R status. These parametric studies provided insights to the project committee that was needed in order to recommend specific and practical solutions to achieve ultra-low EUIs in the multifamily building sector.

Energy Modeling Summary

Extensive energy modeling enabled assessment of multiple energy efficiency strategies that were considered in this design guide. A “typical” prototype model was developed to represent a 52,000 ft^2, market-rate, 4-story multifamily building. This building topology was selected to create a building that is evaluated with the commercial building code versus a low-rise residential building which follows residential building codes. The model included a mix of specifications from the residential BEopt (BEopt 2020) energy modeling software and the commercial OpenStudio energy modeling platform (OpenStudio 2020) – both use EnergyPlus as the simulation engine (EnergyPlus 2020).

The first floor of the prototype model consists of commercial space including light retail, common and community spaces, a small office, lobby, gym, and space allocated to mail and garbage disposal. The upper three floors consist of a mix of studio, 1-bedroom, 2-bedroom, and 3-bedroom residential apartment units. The prototype model also included two elevators and stair access. ASHRAE Standard 90.1-2019 (ASHRAE 2019b) provided input parameters as an initial starting point. In other words, the modeled buildings had to meet or exceed current standards. Table 1 describes high-level parameters that were used in the model. Table 2 provides detailed information about the space types considered in both the commercial and residential floors of the multifamily model.

Table 1. Multifamily characteristics used in modeling

Characteristic	Market Rate Multifamily Building
Size	52,000 ft^2
Number of floors	4
Number of apartments per floor	15 (studio, 1, 2, and 3 bedrooms)
Window-to-wall ratio	30%
Wall construction	Steel-framed
Roof construction	Insulation entirely above deck

Table 2. Space type breakdown by floor in design guide simulation

Space Type	Commercial Floor		Residential Floor*	
	Area (ft²)	Percentage of Total	Area (ft²)	Percentage of Total
Stairs	600	5%	600	5%
Elevator	200	2%	200	2%
Corridor	1,000	8%	800	6%
Retail	4,600	35%	-	-
Coffee Shop	1,500	12%	-	-
Mail/Shipping	450	3%	-	-
Lobby	600	5%	-	-
Bathroom	300	2%	-	-
Garbage	450	3%	-	-
Office	750	6%	-	-
Gym	1,050	8%	-	-
Community Room	1,500	11%	-	-
Studio Apartment (4 units/floor)	-	-	1,800	14%
1-Bedroom Apartment (7 units/floor)	-	-	4,650	36%
2-Bedroom Apartment (3 units/floor)	-	-	3,450	26%
3-Bedroom Apartment (1 unit/floor)	-	-	1,500	11%
Total	13,000	100%	13,000	100%

*Note that the simulation models included 3 residential floors and 1 commercial floor. The data provided here represents 1 residential floor.

The energy modeling analysis was conducted in all nineteen ASHRAE climate zones, because different climate zones yield different solutions and energy targets, and the guide is inclusive of multifamily design in any location. Table 3 provides the representative city and weather file name for each climate zone.

Getting to Zero Energy

To develop the multifamily ZE AEDG, project committee members built upon new, advanced, and proven high-performance technologies and strategies, as well as successful design and construction approaches from existing high performance and ZE multifamily building case studies cited in (NBI 2018) and beyond. The new guide contains guidance to help project teams get to zero by considering various efficiency technologies, equipment parameter improvements, design refinements, and other ZE/R related guidance. A few examples are discussed in the following sections.

Plug Loads

As building systems become more and more efficient, plug-in loads (plug loads) are starting to consume a much larger portion of whole building energy. When achieving ultra-low EUIs, it is particularly important to focus on procuring the most efficient equipment possible. For example, the multifamily ZE AEDG energy models accounted for ENERGY STAR (ENERGY STAR 2020) or CEE TIER 1 and TIER 2 equipment (CEE 2020) – the highest performing equipment on the market. Even with these energy specifications, the models show that plug loads consume 30 to 44% of whole building energy (depending on climate zone) in the most high-performing cases. Thus, high-performing multifamily buildings are internally load dominated due to the large number of large appliances in each apartment unit. Appliances such as induction cooktops, convection ovens, heat pump clothes dryers, and ENERGY STAR rated microwaves, dish washers, clothes washers, and refrigerators should be heavily considered.

Table 3. Climate zones represented in the design guide

Climate Zone	Location	Energy Plus Weather (EPW) Filenames
0A	Hanoi	VNM_Hanoi.488200_IWEC.epw
0B	Abu Dhabi	ARE_Abu.Dhabi.412170_IWEC.epw
1A	Honolulu	USA_HI_Honolulu.Intl.AP.911820_TMY3.epw
1B	New Delhi	IND_New.Delhi.421820_ISHRAE.epw
2A	Tampa	USA_FL_MacDill.AFB.747880_TMY3.epw
2B	Tucson	USA_AZ_Davis-Monthan.AFB.722745_TMY3.epw
3A	Atlanta	USA_GA_Atlanta-Hartsfield-Jackson.Intl.AP.722190_TMY3.epw
3B	El Paso	USA_TX_El.Paso.Intl.AP.722700_TMY3.epw
3C	San Diego	USA_CA_Chula.Vista-Brown.Field.Muni.AP.722904_TMY3.epw
4A	New York	USA_NY_New.York-J.F.Kennedy.Intl.AP.744860_TMY3.epw
4B	Albuquerque	USA_NM_Albuquerque.Intl.AP.723650_TMY3.epw
4C	Seattle	USA_WA_Seattle-Tacoma.Intl.AP.727930_TMY3.epw
5A	Buffalo	USA_NY_Buffalo-Greater.Buffalo.Intl.AP.725280_TMY3.epw
5B	Aurora	USA_CO_Aurora-Buckley.Field.ANGB.724695_TMY3.epw
5C	Port Angeles	USA_WA_Port.Angeles-William.R.Fairchild.Intl.AP.727885_TMY3.epw
6A	Rochester	USA_MN_Rochester.Intl.AP.726440_TMY3.epw
6B	Great Falls	USA_MT_Great.Falls.Intl.AP.727750_TMY3.epw
7	International Falls	USA_MN_International.Falls.Intl.AP.727470_TMY3.epw
8	Fairbanks	USA_AK_Fairbanks Intl.AP.702610_TMY3.epw

Water Heating

Historically, domestic water heating has been one of the largest energy end-use components in multifamily buildings, in particular those that use traditional gas fired boilers. However, with the advancement of electric heat pump water heaters, energy needed to heat water has been drastically reduced. Water heating systems recommended in the multifamily guide include various electric heat pump water heater systems and considerations for incorporating sewer heat recovery systems as well.

Lighting

Electric lighting energy has significantly decreased as LEDs have taken over the market. Ultra-low lighting power densities are recommended in the multifamily ZE AEDG, ranging generally from 0.2-0.5 W/ft^2, which are easily achieved using 100% LEDs and careful control design in appropriate spaces. This is significantly lower than those prescribed by ASHRAE Standard 90.1-2019 (ASHRAE 2019b). Sample design strategies are provided in the AEDG to show how these lighting power densities can be achieved. Daylighting and daylighting controls can also contribute to energy savings, especially in allocated commercial spaces.

Envelope

A tight, well-insulated envelope is a critical element in any energy-efficient building. Setting an absolute energy goal (Leach et al. 2012) before design begins shifts the burden of responsibility for meeting that goal from the owner to the project team. The multifamily ZE AEDG provides recommendations based on an extensive multi-variable parametric energy modeling study that considered envelope and fenestration insulation values ranging from ASHRAE 90.1-2019 (ASHRAE 2019b) to values compliant with the Passive House Standard (PHIUS 2020). The recommended values also consider a balance of energy savings and diminishing returns; increasing insulation beyond a certain amount may not provide significant benefit for the cost.

Heating, Ventilating, and Air Conditioning

Several HVAC systems were considered in the multifamily ZE AEDG. Ultimately system selection depends on the building configuration, owner preference, zone configuration, and the magnitude of the loads to be served. However, the design guide (backed by energy modeling results) recommends three systems: (a) air-source heat pump multi-split systems, (b) water-source heat pump systems, and (c) four-pipe hydronic systems. All systems incorporate a dedicated outdoor air system with either heat or energy recovery ventilation. Note that these systems are only examples and are used to determine the EUI targets. Other configurations of systems may be used to achieve the EUI targets but are not covered explicitly in the guide.

Getting to Zero

The objective of the simulation analysis was to create a set of climate-specific, ultra-low EUI targets for ZE/R multifamily buildings. Through parametric analysis, the project committee was able to explore energy impacts of different system types and use the analyses to determine the most energy-efficient options that are also cost effective.

Once a building achieves ultra-low EUI targets, project teams must then determine how much solar is required to get from ZER to ZE. To provide guidance on this process, the NREL analysis team used the PVWatts Calculator (PVWatts 2020) to determine the possible generation capacity (kBtu/ft^2) of solar photovoltaic systems. This PVWatts analysis assumed 20% efficient panels in a flat orientation covering the roof. Using the outcomes of this analysis, the NREL team calculated the amount of PV area needed as a percent of the total building floor area to offset the building's expected energy consumption. For example, in climate zone 4B, a 4-story building requires 64% of the roof to be covered with PV. In extreme climate zones, the building site might be needed to host additional PV panels depending on the number of stories and the rooftop availability. This information, along with site and source EUI targets, are provided in Table 4 for each climate zone. Note that the source EUI targets are listed as the site-source conversion is an important part of achieving ZE using DOE's ZE definition (DOE 2015).

Table 4. Multifamily ZE/R energy use intensity targets

Climate Zone	Multifamily Site EUI (kBtu/ft²·yr)	Multifamily Source EUI (kBtu/ft²·yr)	PV Area as Percent of Total Floor Area
0A	28	86	31%
0B	29	90	21%
1A	26	82	20%
1B	27	85	24%
2A	26	80	21%
2B	23	73	17%
3A	23	71	21%
3B	22	69	16%
3C	20	71	16%
4A	23	69	22%
4B	21	68	16%
4C	21	65	25%
5A	22	69	23%
5B	22	68	18%
5C	20	62	23%
6A	24	75	24%
6B	22	71	23%
7	24	75	26%
8	25	80	38%

Additional Considerations for Variations in Multifamily Building Business Models

Many business models for multifamily projects and the project committee realized that EUI values can vary significantly depending on variables such as the density of apartment units in a building. The EUI targets in Table 4 apply to more typical market rate buildings, due to the mix of apartment types. In affordable housing, there's often a heavier, high-density mix of studio and one-bedroom apartments. Luxury, high-end apartments are likely to have a lower density mix of two and three-bedroom apartments. Because high-performing multifamily buildings with appropriate envelopes are internally load dominated, this mix of units greatly affects energy consumption related to appliances and hot water consumption, which are two significant energy end-uses in this building sector. To understand the effects of density, the committee assessed how EUI changes in high, medium, and low-density scenarios. The medium density scenario reflects the same mixed floor plan used to derive the final EUI targets (a mix of 15, studio, one, two, and three-bedroom apartment units per floor). The high-density scenario floor plan includes a mix of 20 studio and 1-bedroom apartment units per floor. The low-density scenario floor plan includes a mix of 9, two and three-bedroom apartment units per floor. The resultant site EUI values are found in Figure 1.

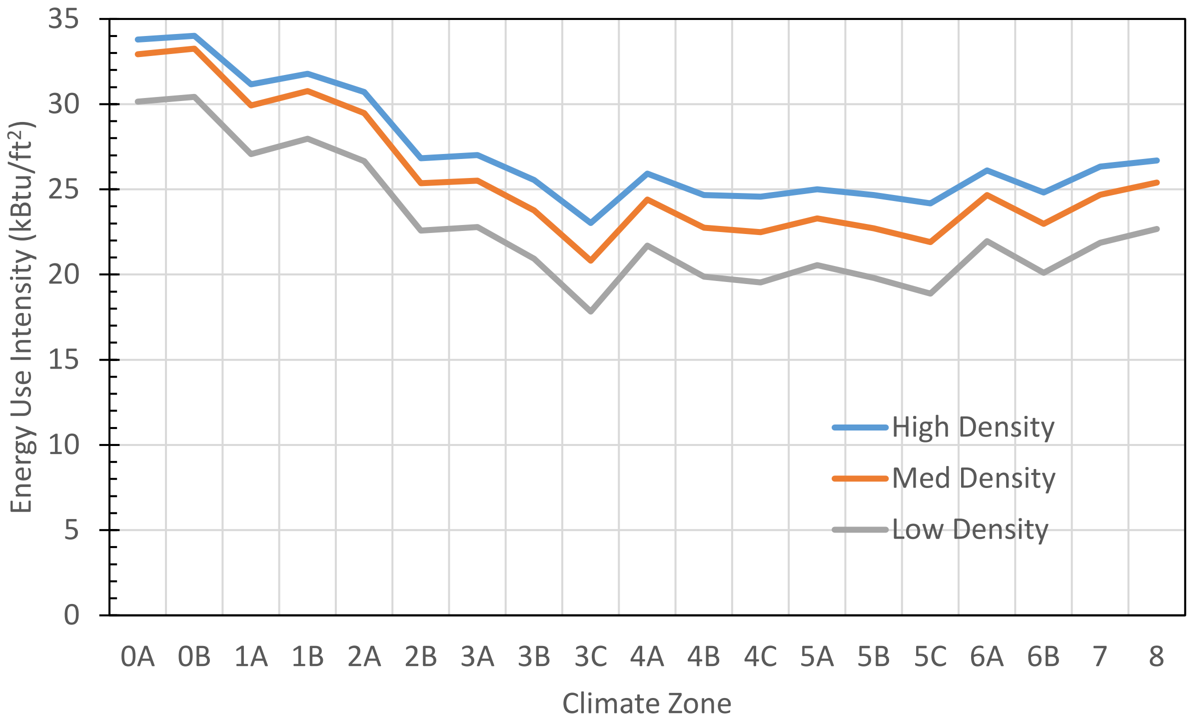

Figure 1. Site EUI values per climate zone for a low, medium, and high-density apartment unit structure

In addition, the project team separated residential EUI targets from the commercial space, to accommodate multifamily buildings that do not include commercial space. These split and combined EUI targets (site and source) are shown in Table 5.

Replication

The modeling process was conducted in a manner where OpenStudio measures can be shared publicly in ways that the design community can integrate the measures into their own building simulations. These capabilities will be incorporated into future releases of OpenStudio (OpenStudio 2020). In addition, it's encouraged that the design community go a step further and introduce improvements by investigating alternative strategies while continuing to achieve the design EUI goal. This outward facing process allows the design community to apply the prescriptive recommendations to their own building layouts and operational schedules. One example is to use the simulation models and EUI targets as a teaching tool as part of the Solar Decathlon Design Competition.

Table 5. Multifamily ZE/R energy use intensity targets,

Climate Zone	Residential Site EUI (kBtu/ft²·yr)	Commercial Site EUI (kBtu/ft²·yr)	Combined Site EUI (kBtu/ft²·yr)	Residential Source EUI (kBtu/ft²·yr)	Commercial Source EUI (kBtu/ft²·yr)	Combined Source EUI (kBtu/ft²·yr)
0A	23	41	27	72	126	86
0B	27	36	29	83	113	90
1A	25	30	26	78	92	82
1B	25	34	27	78	106	85
2A	24	30	26	76	90	80
2B	23	24	23	73	73	73
3A	22	28	23	68	81	71
3B	20	29	22	63	88	69
3C	20	19	20	67	83	71
4A	21	28	23	65	82	69
4B	21	24	21	65	76	68
4C	21	20	21	67	58	64
5A	21	26	22	64	85	69
5B	20	28	22	62	87	68
5C	20	19	20	63	56	61
6A	21	32	24	66	102	75
6B	22	24	22	69	75	71
7	23	26	24	72	87	75
8	22	34	25	69	113	80

Conclusion

In developing the multifamily ZE AEDG, ZE/R EUI targets for 19 climate zones were determined such that the EUIs can be balanced with on-site renewable energy resources. The energy modeling analysis established that it is technically possible for new multifamily construction projects to achieve ZE/R status in all climate zones across the continental United States. For some climate zones and for taller buildings, PV on-site is needed to augment roof area. An alternative is PV on the building façade. When achieving such aggressive EUI targets, plug-in equipment, appliances, and hot water heating become important end-uses to focus on.

When reaching ZE status, temperate climates require a smaller percentage of solar panel coverage than very hot or very cold climates. Extremely cold climates (climate zone 8) have large energy needs and limited solar resources so roof space alone often is not enough area for solar generation.

The target EUIs developed in this study and design guidance in the AEDG provide excellent starting points for all multifamily owners who want their projects to be as energy efficient as possible. Providing data- and subject matter expert-driven insight to industry enables design teams to start with viable pathways to ZE and adjust those pathways based on local market conditions and needs.

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