Integrated Packages for Advanced Buildings towards ZNE

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ABSTRACT

Various jurisdictions have set forth aggressive goals for advanced buildings, including California's goal for all nonresidential new construction to be zero net energy (ZNE) by 2030. To achieve these objectives, particularly in a cost-effective manner, buildings will need to move beyond measure-level strategies.

This paper presents findings from a study that reviewed case studies and conducted interviews with 39 project team members representing 29 advanced (ZNE and near ZNE) nonresidential buildings in California. We present trends from these advanced buildings, including project goals related to ZNE, overall design processes and the use of integrated design, and the occurrence of specific measures.

We discuss how these advanced strategies and measures can be combined into integrated design packages to further optimize energy efficiency, with a focus on HVAC strategies. We explore examples of "mixed mode" buildings that combine passive heating and cooling strategies with active systems, radiant cooling, and daylighting. In addition, we use case studies to illustrate the importance of enabling technologies (such as ceiling fans, window switches, and controls) to promote holistic success.

Finally, we discuss challenges with these integrated systems, including modeling limitations for energy, occupant comfort, and daylighting, and discuss how incentive programs can help address the challenges and accelerate the use of these integrated packages. Results summarize deep energy saving approaches that will inform emerging technology research, incentive programs, and programs that encourage ZNE.

Introduction

Advances in building energy efficiency design approaches and policy are needed to meet aggressive zero net energy (ZNE) goals, such as the California ZNE goal for all commercial building new construction by 2030 (Engage360 2011). Many ZNE and near-ZNE commercial buildings (referred to here as "advanced buildings") have been constructed in California. The design concepts and practices used for these buildings need to be learned to inform building standards development, create opportunities for above-code programs, and prioritize emerging technology) research. While this study was funded to focus on California buildings, the results are widely applicable in other locations due to the diversity of climates represented.

This study originally sought to catalogue individual systems and strategies. However, interviewees stressed the importance of integrated design to make strategic decisions that optimize overall building performance, meet occupant and owner needs and goals, and balance energy performance with project budget. Consequently, we analyze how individual measures and strategies are combined into integrated design packages (IDPs) with deeper efficiency potential than isolated measures. We also identify the necessary considerations and enabling elements to successfully implement an IDP. In this paper, we:

- Identify individual energy efficiency measures in advanced buildings.

- Identify integrated design packages (IDPs) commonly used in advanced buildings to optimize whole building performance, and discuss their features.
- Discuss challenges to, and implications of, implementing these IDPs, and
- Identify policy opportunities to support advanced efficiency approaches including IDPs.

Methodology

We began by identifying nonresidential advanced buildings that have been constructed or undergone a major renovation in California, focusing on buildings constructed in the past five years (2010 – 2015). We used several sources to identify projects, including New Buildings Institute's (NBI) California ZNE Watchlist (2015) and U.S. Department of Energy's (DOE) High Performance Building Database (2015), among others.[1] In developing a list of advanced buildings, we sought to include a mix of building types and advanced measures, and only included buildings with low projected Energy Use Intensity (EUI)[2].

To collect building-level data, we conducted phone interviews with 39 project team members representing 25 advanced buildings. We also leveraged data that NBI collected for four additional buildings, for a total of 29 advanced buildings surveyed. We interviewed architects, engineers, and energy modelers, as well as a few facility managers and owners / developers. The interview topics included project goals, details on the measures and strategies used in the advanced building, and how energy code requirements (including compliance software capabilities) support or hinder advanced design solutions. In addition to interviews, we reviewed case studies and other project materials with design and performance data.

The 29 advanced buildings represent a range of commercial building construction, as seen in Figure 1.

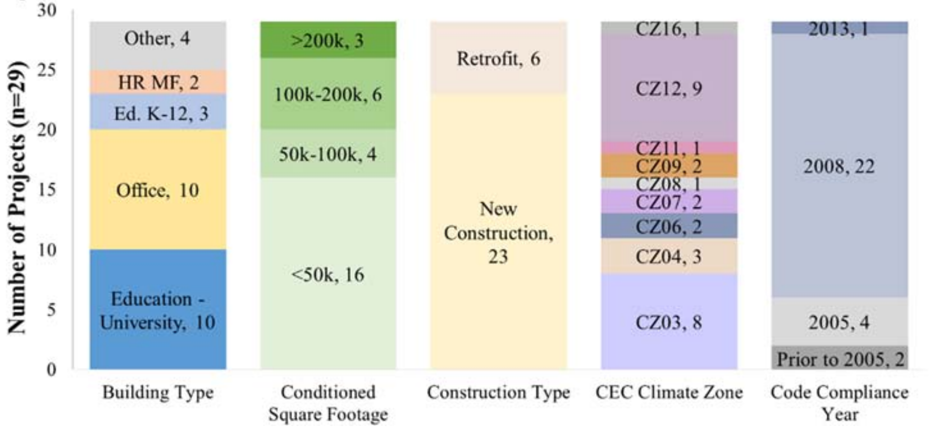

Figure 1. Number of projects by building type, conditioned floor area, construction type, climate zone, and code compliance year.

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[1] U.S. Green Building Council LEED Directory (http://www.usgbc.org/projects) and Savings By Design Energy Efficiency Integration Award Winners (http://www.savingsbydesign.com/award-winners/2011).

[2] The average modeled EUI of projects studied is less than 40 kBtu/ft^2 prior to site energy generation. Measured EUI data was not collected.

Most projects studied targeted ZNE-site[3] (14 projects) and LEED certification (18 projects). Other common goals were ZNE-electric[3] (seven projects) and ZNE-bill[3] (three projects). In addition to LEED certification, projects participated in International Living Future Institute (ILFI) and Collaboration for High Performance Schools (CHPS) certification programs. Five projects also set goals for carbon neutrality and reduced greenhouse gas emissions.

Measure Level Results

We begin by presenting the occurrence of each strategy, system, or measure in isolation. Note that the sample size for strategies may be less than 29, because we were not able to identify all strategies used for all projects. We may also be underestimating the number of projects using each strategy because we did not have sufficient time in each interview to ask about each and every measure. As an overall trend, we found that many projects emphasize passive strategies for cooling, ventilation, and daylighting.

Cooling Strategies

Study projects used passive, mixed-mode, and active cooling strategies, defined as:

- Passive cooling: refers to when cooling is provided entirely with outside air from operable windows/vents by passive means or with fan assistance.
- Mixed mode: refers to "a hybrid approach to space conditioning that uses a combination of natural ventilation from operable windows (either manually or automatically controlled), and mechanical systems that include air distribution equipment and refrigeration equipment for cooling" (CBE 2013).
- Active: refers to compressor-based cooling.

Mixed-mode approaches are commonly classified into three groups based on their HVAC versus natural ventilation control strategies. "Concurrent" mixed-mode describes HVAC and passive operation in the same space at the same time. "Change-over" mixed-mode describes HVAC and passive in the same space operated at different times. "Zoned" mixed-mode describes HVAC and passive operation in different spaces at the same time, where different zones in the building use different cooling strategies. A project that is mixed-mode by zone has at least one zone that is entirely passive.

As shown in Table 1, less than one-third of the projects use only active cooling, and the majority (71%) use passive cooling (including through mixed-mode). Of the 17 mixed-mode buildings, six use "concurrent", eight use "changeover", and three use "zoned" approaches. Out of the six active HVAC only projects and the 17 mixed-mode projects, 11 have radiant cooling.

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[3] ZNE-site is defined as a building that produces at least as much energy as it uses on-site annually. ZNE-electric is defined as a building that produces at least as much electricity as it uses on-site annually. ZNE-bill is defined as a project that exports enough energy to the grid to offset the annual cost of energy under a utility payback agreement.

Table 1. Overall cooling strategy used in sample projects.

Cooling Strategy	Number of Projects	Percent of Projects (n=25)
Passive Only (compressorless)	1	4%
Mixed-Mode (by zone)	3	13%
Mixed-Mode (concurrent, changeover)	14	58%
Active HVAC Only	6	29%

One-third of projects' cooling systems include thermal energy storage (TES). The TES type is about evenly divided between chilled water storage tanks (five projects) and night pre-cooling with thermal mass (four projects), for a total of nine projects.

Lighting Strategies

Daylighting, as a general strategy, is identified in 27 of the 29 projects. To implement daylighting, 23 projects use solar control measures to reduce direct solar radiation through fenestration through building orientation, window and skylight placement, overhangs, exterior shading, and high performance or dynamic glass. Other daylight quality and quantity measures include narrow floor plate (two projects), light shelves or clerestories (nine projects), and skylights (ten projects). Advanced buildings almost always included lighting controls (occupancy sensors in 19 project, photocells in 16 projects, and continuous or multi-level dimming controls in 14 projects), as well as high efficacy lighting (including LEDs or high efficacy linear fluorescents in 21 projects). In addition, six projects (one-fifth) identified the use of task lighting.

Building and System Controls

Out of the 25 projects with known control systems, most projects (21 out of 25) have centralized control, 13 of which are fully integrated to control lighting and HVAC, and eight that control HVAC only. The remaining four projects have only localized controls for HVAC and/or lighting. Interviewees reported that controls are important for properly integrating passive with active systems, such as disabling HVAC in response to open windows.

Integrated Design Packages Results

The motivation for this study was to identify deep efficiency solutions to meet California ZNE goals which require building efficiency to improve at an accelerated pace (Engage360 2011). Our findings indicate that "Integrated Design Packages" (IDPs) were important to achieve energy goals cost effectively. This study defines IDPs to be integrated solutions using a group of measures that are high performance, when combined that may not be feasible or cost effective in isolation. For example, providing 100% of cooling with cool water produced only by evaporation (compressorless) becomes feasible when designed with large active radiant surfaces that effectively cool with higher temperature water than a conventional coil/air based system. Thus, structural mass embedded radiant systems (large surface area) served by cooling tower water (no compressors) creates an IDP with deeper energy savings than either measure in isolation.

Integrated Design as a First Step towards IDPs

We found that an integrated design process underpins IDP solutions. Most interviewees emphasize the importance of an integrated process, in which multiple disciplines interact in an iterative process to find optimum solutions. Designers expressed a need for flexible strategies that take a holistic approach rather than focusing on specific measures in their particular discipline. Multiple project teams also told us that specific ZNE goals or EUI targets drove the integrated design process and required out of the box thinking by the entire team.

Common IDPs in Advanced Buildings

We identified three commonly occurring IDPs in the advanced buildings surveyed that employ three foundational measures: passive or mixed-mode cooling, radiant cooling, and daylighting, as shown in Table 2. The IDPs are comprised of the foundational measures in combination with complementary additional measures. We categorize these features into “essential elements” that are critical for the IDP, and “alternatives/ variations” that are synergistic with the IDP. “Essential elements” are features that combine to make an IDP with benefits beyond any individual measure (they are the IDP), while “alternatives/variations” are non-essential additional measures that fit well with the IDP. No one set of measures can perfectly address the various types of commercial buildings, thus the optimal combination of measures in the IDP is based on meeting the needs and opportunities of each project. There are instances when one measure provides an opportunity for two IDPs, such as a narrow floor plate, which increases the proportion of a building that can be daylit and naturally ventilated. Each measure in Table 2 is described in more detail in subsequent sections. Note that these are only three of many possible strategies for advanced buildings, although they are used in 27 out of the 29 buildings we examined.

In addition, we found that three enabling elements recurred throughout the IDPs to help ensure their success. These were: more focus on controls systems and commissioning, occupant centric design solutions, and cooling load reduction. Cooling load reduction was critical for radiant cooling and passive cooling because they have lower cooling capacity than conventional systems. Each of the IDPs, as well as the enabling elements are discussed in more detail in subsequent sections.

Table 2. Common IDPs: essential elements and alternatives/variations.

Passive (natural) or Mixed-Mode cooling IDP (n=18)[1]	
Common Essential Elements	Alternatives/Variations
• solar control (n=15) • reduce plug load (n=6) • mass (n=3) • ceiling fans (n=8)	• night pre-cooling (n=6) • automated window or louver (n=4) • narrow floor plate (n=2)

Radiant Cooling IDP (n=11)[1]	
Common Essential Elements	Alternatives/Variations
• solar control (n=9) • reduce plug loads (n=4) • evaporatively cooled water (compressorless) (n=2)	• mixed-mode: passive + radiant (n=7) • ceiling fans (n=4) • thermal energy storage (n=4) • night pre-cooling (n=1) • heat pump (bay water, geothermal) (n=5)

Daylighting IDP (n=27)	
Common Essential Elements	Alternatives/Variations
• solar control (n=23) • light shelves or clerestories (n=9) • high efficacy lighting (n=21) • controls (n=19)	• occupant response controls (n=19) • skylights (n=10) • narrow floor plate (n=2)
[1] Building counts are not mutually exclusive. For instance, a project that is mixed-mode with passive and radiant cooling is counted in both the passive cooling and radiant cooling project counts.	

Passive and mixed-mode cooling IDPs. As shown in the results section and Table 2, a large proportion of projects incorporated passive cooling, mostly using a hybrid "mixed-mode" approach. Only a few have at least one zone or all zones entirely cooled by passive means.

Mixed-mode literature and case studies point to advantages of energy savings (from partial elimination of active cooling) and increased occupant satisfaction due to occupant centric design (operable windows and connection to outdoor climate) (Ring 2000; Brager 2008). Literature also describes significant challenges and barriers to mixed-mode, primarily design and controls complexity when two systems interact and lack of predictive design tools (CBE 2013). Mixed-mode designers have stated that the combination of passive and active systems can be, "the best of both worlds" or "the worst of both worlds" (Paliaga 2009).

In this study, we observed many similar and recurring features in projects that use passive and mixed-mode cooling strategies. Essential elements of passive and mixed-mode IDPs include solar control, reduced plug loads, thermal mass, and ceiling fans. Variations that apply to mixed-mode designs include nighttime pre-cooling, and automated windows/louvers. Frequency of occurrence of these measures is included in Table 2. Table 3 summarizes specific project design solutions observed in study projects.

Table 3. Example passive and mixed-mode integrated designs from specific study buildings.

1	Load reduction using: (a) envelope with orientation specific glazing and overhangs, (b) daylighting. Thermal comfort is provided without compressors by (a) fan assisted passive cooling using an outside air only AHU, (b) thermal mass pre-cooled at night, (c) ceiling fans with automatic comfort control.
2	Load reduction using: (a) envelope with high performance glazing, clerestory windows, 40% window to wall ratio (WWR) mostly facing north, (b) daylighting. Zoned mixed-mode HVAC system with (1) perimeter passive cooling, (2) interior mechanical VAV, (3) radiant system in child daycare zone. Natural ventilation is enhanced with automated windows and louvers.
3	Load reduction using: (a) envelope with high performance triple pane glazing, overhangs, shading by surroundings, and sealed to passivhaus standards, (b) daylighting, (c) decrease plug loads by forbidding some equipment and off-siting servers. Change-over mixed-mode HVAC system with 3-step conditioning: (1) passive cooling through manual windows, (2) supplemental radiant ceiling when needed, (3) VRF for special high load occasions with large number of occupants.
4	Load reduction using: (a) envelope with electrochromic glazing, sloped skylights, external window shading, and high wall insulation, (b) daylighting, (c) reduce plug loads with behavior modification using meters and occupant dashboard. Change-over mixed-mode HVAC system that maintains occupant comfort with: (a) Passive cooling through manual windows, (b) Desk and ceiling fans, (c) night flush and thermal mass (d) Packaged AC cooling when needed (estimated 15% of time).

Radiant cooling IDPs. Radiant cooling systems provide an opportunity to achieve significant energy savings, peak demand reductions, and load shifting. Radiant systems circulate water through panels or the building structure. Large areas of radiant surfaces enable cooling with water that is much closer to the desired air temperature than typical HVAC chilled water, resulting in many opportunities for low energy solutions such as evaporative only (condenser water) cooling, ground-source or lake/bay heat exchangers, and cascaded chilled water system (water serves coils and then radiant floor in series). Studies have demonstrated 34% energy savings with higher occupant satisfaction (Sastry and Rumsey 2014) and a NBI study of 160 ZNE buildings shows an increased adoption of radiant systems (NBI 2014).

While radiant cooling has promise, there remain significant market barriers. The California Energy Commission recently funded a research project to address market barriers to radiant systems including: engineering fundamentals for sizing, controls and operation, documentation of case studies, and software design tools (CEC-EPIC 2014).

Essential elements of radiant cooled IDPs include load reduction (solar control and reduced plug loads) and use of evaporatively cooled water (i.e., the fluid used in radiant cooling is cooled without a compressor). Variations include mixed-mode (see previous section), ceiling fans, thermal energy storage, night pre-cooling, and ground or bay water source heat pumps. Frequency of occurrence of these measures is included in Table 2. Table 4 summarizes specific project design solutions observed in study projects.

Table 4. Example radiant cooling integrated designs from specific study buildings.

1	Load reduction using: (a) envelope with high performance triple layer (heat mirror) glazing, 30-40% WWR, continuous external insulation to reduce thermal bridging, clerestory windows, exterior fixed shades and automated louvers, (b) daylighting, (c) reduce plug loads by specifying ENERGY STAR® equipment. Radiant panel cooling with water cooled at night by cooling tower and stored in tanks. Chilled beams in high load space. Dedicated outside air ventilation.
2	Load reduction using: (a) envelope with high performance glazing, 40% WWR, automated and manual interior shades, (b) daylighting, (c) controlling plug load outlets with building controls. Radiant floors embedded in structural slab serviced by a heat pump (cooling and heating) using bay water as a heat sink. Supplemental cooling with radiant ceiling panels in high load space. Dedicated outside air with displacement ventilation.
3	Load reduction using: (a) envelope with high performance glazing chosen by orientation, recessed north and south windows, brise-soleil to south, high wall insulation, (b) daylighting. Radiant floors with cooling provided by ground source heat pump. Natural ventilation using automated windows with mixed-mode control. Additional comfort control with ceiling fans. Supplemental cooling with chilled beams in high load space.

Daylighting and lighting controls IDPs. In the 2008 Commercial Building End Use Consumption Survey (CBECS), lighting comprised 25% of commercial building energy use in the United States (EIA 2008). Rapid advances in lighting technologies are reducing electrical lighting energy use in commercial buildings, but there are opportunities for additional savings with lighting controls and daylighting. As the NBI Continental Automated Buildings Association (CABA) study concluded, “Daylighting is critical to ZNE” (Higgins 2014). Daylighting can reduce the need for electric lighting during the day when commercial buildings are generally occupied.

To optimize daylighting, a number of factors and features must be combined to control the quality and quantity of daylight in a space, as shown in the daylighting IDP. Best practice identified through project team interviews is to consider building orientation, size, and fenestration placement during the initial design; narrow buildings and clerestories are successful strategies if they are feasible to implement. The next IDP consideration is the quality of incoming light to provide a comfortable and useable space for occupants. As a lighting designer mentions, “the control of daylight is equally if not more important.” Glare and solar heat gain from direct sunlight can cause occupants to close blinds and use electric lighting. To avoid this, successful implementation of daylighting often includes solar control measures such as overhangs, exterior shading, louvers, and high performance glazing.

Finally, to optimize the IDP, project teams introduce lighting controls and high efficacy lighting to reduce electric lighting consumption when it is needed. We heard from lighting designers that lighting controls are one of the biggest challenges, but are fundamental for ZNE buildings and can make a profound difference. The benefits of daylighting cannot be fully captured unless appropriate controls (photocells and dimming controls) are installed and carefully commissioned. The control of daylight quantity and quality and the inclusion of high efficacy lighting and controls contribute to load reduction, which is critical for the passive, mixed-mode, and radiant cooling IDPs.

Essential elements of daylighting IDPs, as described above and shown in Table 2, include solar control, light shelves or clerestories, high efficiency lighting, and controls that are commissioned by zone based on daylight availability and occupancy. The main variations are the addition of occupant centric lighting (task lighting, occupancy controls), skylights, and narrow floor plates. Frequency of occurrence of these measures is included in Table 2. Table 5 summarizes specific project design solutions observed in study projects.

Table 5. Example daylighting integrated designs from specific study buildings.

1	Daylighting coverage increased with narrow building plate, light shelves, skylights. Glare controlled with exterior shading. Lighting provided by high efficacy linear fluorescents with stepped-dimming controls, photocells, occupancy sensors. Task lighting to reduce ambient lighting.
2	Daylighting coverage increased with open office plan, light shelves, light-reflective concrete, transparent stairwells. Glare control with exterior fins and automated shades. Lighting provided by LEDs with dimming ballasts. Task lighting automatically shut-off based on occupancy.
3	Daylighting coverage increased with light shelves and orientation-specific glazing room-by-room. Glare control with overhangs, interior shading. Automatic dimming lighting controls.

Challenges and Opportunities

Enabling Elements of Integrated Design Packages

Design teams are challenged by the complexity, risk, and tight integration required to design buildings with IDPs. We identified the following enabling elements that were important for the study buildings to successfully implement low energy IDPs. These elements are important considerations for all IDPs and projects with ZNE or low energy use goals.

Controls are critical. Design teams consistently told us that controls are critical for high performance buildings and that proper control design and implementation is a challenge for innovative designs. Emphasis on the importance of controls is supported in the recently completed NBI study for CABA (Higgins 2015). The CABA study states that controls are the "nexus of energy performance". Similarly, we heard from interviewees in this study that controls were often the largest challenge and required extra effort to design and commission so that the buildings would operate in an integrated way. One designer summarized the importance of controls for IDPs by saying, "The project had a goal of compressorless cooling. It was very in-depth with the daylighting design and controls. It was laborious to go room by room [doing daylighting calibration], but very worthwhile in order to shut off lights in the middle of the day which was crucial to the cooling strategy. I have never seen a project go this far."

A significant barrier to ZNE and near ZNE buildings is the challenge and risk around control system performance. The IDPs identified in this study include innovated design strategies (radiant, passive systems, daylighting) tightly integrated with other building features, which requires novel controls with more sophistication than conventional buildings. For instance, window switches that sense when windows are open and disable HVAC systems are important to limit waste in mixed-mode buildings with concurrent operation and to limit peak load in radiant buildings. A key assumption of the IDP concept is that the combination of measures is better than the sum of the parts, which requires a well-integrated and commissioned control system.

Occupant centric solutions. Many projects used occupant centric solutions that provide services (light/heat/cool) to the occupant rather than to the building including: task ambient lighting; ceiling/desk fans for task ambient cooling; allowing occupants to change their location; occupancy sensors controlling lighting, cooling, and plug loads; and operable windows. Providing services to the occupant rather than the building can result in energy savings and peak load reduction (internal loads are reduced). Peak load reduction is often necessary for radiant cooling and passive cooling IDPs because both strategies have limited cooling capacity and response time.

All three IDPs can result in indoor environmental quality (IEQ) conditions that are more variable than conventional solutions due to their passive nature or slow responding thermal mass. Occupant centric solutions have been shown to improve satisfaction and acceptance across a wider range of conditions (Brager 2004; Bauman 1998). This can be as simple as providing desk fans to maintain comfort with passive and radiant systems. A recent study of IEQ in mixed-mode buildings concluded that, “the best [mixed-mode] performers were those that were newer, in more moderate climates, had radiant cooling or mechanical ventilation only, and allowed high degrees of direct user control ...” (Brager 2008). Thus, a focus on occupants may be critical for achieving high IEQ performance in advanced buildings that use passive and radiant systems.

Designers described a need for input and buy in from owners for unconventional designs, including discussion of comfort performance targets and expectations, and expressed that lack of comfort software tools and comfort performance metrics was a challenge. Improving comfort performance analysis tools provides two key benefits for advanced design: first is assessment of comfort variability and exceedance for decision making, and second is comparison and tradeoff between design strategies to optimized energy and comfort.

Load reduction. Most project teams stated that reducing peak loads, particularly through plug load reductions and blocking direct solar radiation through windows, was a challenge for the success of the IDPs identified here.

This re-enforces the typical green building tenant of good envelope design that responds to orientation, has moderate glazing areas, and has external shading. Success of radiant cooling and passive cooling require that peak loads are reduced due to significantly lower cooling capacity than conventional systems. Success of radiant cooling requires that loads do not change quickly when sun enters a room because of the slow response of radiant thermal mass.

Strategies used to reduced plug loads included: occupancy sensors that turn off a portion of plug loads when the space is unoccupied, use of ENERGY STAR® products, metering and dashboards to encourage load reduction behavior, prohibition of certain equipment (microwaves, heaters, coffee makers), and limiting the number of computers.

Software and Performance Simulation

Most interviewees reported that they used modeling and simulation for design, because it enabled them to try different measure packages and identify cost effective solutions. However, project teams stated that lack of simulation tools for advanced strategies and code compliance software limitations are significant barriers to incorporating advanced building strategies, as well as the use of integrated packages.

Particular to California, many interviewees stated that California Alternative Compliance Manual (ACM) [4] compliance software rules and Title 24 compliance software[5] limitations are a significant hindrance to advanced buildings. The California ACM does not allow credit for, or accurately reflect, the performance of several common advanced building strategies: Passive

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[4] California compliance software must follow the California ACM (Alternative Compliance Manual) rules.

[5] California certified software prior to the 2013 code (effective 1/1/14) included Energy Pro and eQUEST. Since 1/1/14 the certified software uses CBECC which is based on the Energy Plus engine.

cooling, passive cooling as part of mixed-mode control, air movement for comfort cooling, thermal mass, evaporative cooling, ground source heat pumps, and advanced daylighting design. Compliance software limitations impact code compliance levels, and the total savings claims and incentives paid through above-code programs that rely on compliance software outputs.

In addition, interviewees doubted the accuracy of whole building simulations (E+, eQUEST, ePRO) for all the IDPs we identified: radiant, passive and mixed-mode, and daylighting. Many project teams used stand-alone tools, such as Radiance[6], or custom spreadsheets for advanced strategies because of accuracy concerns with conventional whole building simulations tools, or lack of capabilities to model an advanced strategy.

Another common challenge for ZNE design was lack of capability to predict actual energy consumption for sizing of PV systems, primarily due to lack of reliable plug load data libraries and lack of robust model calibration tools.

Software opportunities. Design software and/or code compliance software should be improved to: (a) improve capability to simulate or accept inputs from tools that model radiant cooling, natural ventilation and mixed-mode, daylighting, and occupant comfort: (b) estimate actual energy consumption with robust plug loads libraries based on real world data, and calibration tools that use existing benchmark databases such as CEUS[7] and CBECS[8].

Knowledge Gaps & Technology Transfer

Many of the measures and integrated strategies used in the study buildings are innovative and designers struggle with lack of knowledge of engineering fundamentals, limited design tools, lack of case studies, and limited contractor or operator experience. Two areas with significant knowledge gaps include: (a) Controls integration and commissioning, (b) lack of knowledge and design tools to support integrated design. In addition, we identified specific measures used in the IDPs that are good candidates for emerging technology research, above code incentive programs, or market education due to their occurrence in advanced designs, but limited overall market presence and performance modeling. These measures include natural ventilation design; mixed-mode systems; radiant cooling design; comfort performance simulation: particularly ceiling and desk fans; task-ambient strategies: both thermal and lighting; occupant responsive controls; daylighting design; and, daylighting controls: particularly commissioning.

Role of Policy

Advanced ZNE and near ZNE buildings are achieving energy efficiency well beyond code requirements and the approaches currently being used can inform policy efforts to rapidly increase efficiency in the larger market. The previous sections summarize opportunities for emerging technology research, incentive programs, education, code readiness programs, and software development. In addition, policy should focus on IDPs because integrated design and integrated packages of measures, rather than isolated measures, are important for deep efficiency results. ZNE code development can use cost effective IDPs, such as the three IDPs identified in this study, to establish efficiency targets or prescriptive packages. Potential integrated design policy efforts include:

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[6] Radiance is a validated lighting simulation tool.

[7] California Commercial End-Use Survey (CEUS)

[8] Commercial Buildings Energy Consumption Survey (CBECS)

- Develop examples, lessons learned, and best practices, for common IDPs that are: (a) encouraged in above-code incentive programs, and (b) used in design guides that project teams use to inform the integrated design process. Teams will start with essential measure and use a list of variations to optimize their building.
- Energy Codes:
    - Set code performance targets using cost effective IDPs. Identify IDPs that have better overall (combined) cost effectiveness than isolated measures.
    - Encourage integrated design, potentially through early stage design requirements for optimization analysis to identify cost effective packages.
    - Emphasize controls integration and commissioning.
    - Develop code compliance software features that support integrated design: one example is software that does parametric optimization analysis including costs. What if code performance software automatically simulated all the IDPs relevant to your building type and produced comparative life cycle cost results?

Conclusion and Recommendations

The design practices and solutions used for advanced and ZNE buildings need to be learned and implemented to achieve ZNE goals. From the study buildings, we identify energy efficiency characteristics and commonly observed integrated design packages (IDPs) that are based on three foundational measures: passive and mixed-mode cooling, radiant cooling, and daylighting. Within each IDP, there are essential measures and alternatives/variations that result in a high performance package greater than the sum of the individual measures in isolation.

Advanced buildings in this study demonstrate market feasible examples (by the very fact that they have been built) and the results suggest that integrated design to create IDPs is important to achieve energy goals cost effectively. We make the following conclusions and recommendations regarding advanced buildings and IDPs.

- Continued research to identify advanced building characteristics and performance to identify opportunities and strategies for ZNE policy.
- IDP concepts should be encouraged and researched through above code programs, emerging technology programs, and market education programs to facilitate future inclusion in codes with a focus on: passive and mixed-mode cooling; radiant cooling; task-ambient strategies (both thermal and lighting); comfort performance simulation; occupant responsive controls; daylighting design; and, daylighting controls and commissioning.
- Code compliance software should be improved to accurately simulate commonly observed strategies, particularly radiant cooling, passive and mixed-mode cooling, daylighting, and occupant comfort.
- IDP concepts can be used to guide policy that focus on optimal packages and performance targets rather than isolated measures.

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