Chapter 3 Findings and Recommendations

The Fort Carson Energy Research Project identified four areas of opportunity to advance buildings to net zero energy (NZE) levels of performance:

1. Thermal envelope optimization
2. Daylighting and lighting system performance
3. Net zero retrofit optimization
4. Occupant behavior

Areas of Opportunity

1. Thermal envelope optimization
2. Daylighting and lighting system performance
3. NZE retrofit optimization
4. Occupant behavior

The four studies in this project were designed based on several principles:

- Identifying strategies that provide optimal energy and cost savings across Fort Carson buildings' lifecycles, up to NZE performance levels;
- Emphasizing occupant needs and feedback; and
- Identifying where Fort Carson research results may be applicable to other military, government, and commercial buildings.

Findings by project follow.

Thermal Envelope Optimization

This study sought to identify:

- Which thermal envelope assemblies provide maximum energy and cost savings over the building lifecycle, and how much they can save compared to buildings that just meet the energy code; and
- Whether and to what extent Fort Carson would benefit from zoning off unused areas of buildings during military deployments and setting back HVAC controls within those areas.

NREL incorporated actual performance and cost data into existing Army Corps of Engineers energy models of five relevant building types to evaluate the performance of a variety of wall, roof and window constructions. The five Fort Carson building types included:

1. Headquarters (HQ: mostly office and training space),
2. Company Operations Facilities (COFs: a mix of office and storage space),
3. Dining Facilities (DFACs: cafeterias),
4. Tactical Equipment Maintenance Facilities (TEMFs: primarily service bays for large vehicles), and
5. Barracks (residential apartment buildings).

The research team used net-present value analysis to determine the most cost-effective solutions over 30-year building lifecycles, compared to the building code baseline (based on ASHRAE Standard 90.1-2007). The materials and components constituting the optimal packages are outlined in the report.

Finding 1: Envelope optimization in new buildings at Fort Carson can yield savings up to 25% over the code baseline with net present value up to $350,000 and simple payback as low as seven years.

Table 23 below estimates performance of the most energy-efficient envelope assemblies for each of the five building types studied:

Table 23 Lifecycle Energy and Cost Savings of Optimal Envelope Packages In Comparison to Building Code Baseline (ASHRAE 90.1-2007)

Building Type	Energy Savings	Incremental First Cost	Annual Energy Savings	30 Year NPV	Simple Payback
Barracks	15.8%	$79,655	$7,652	$82,951	10 yrs
HQ	0.0%	$0	$0	$0	N/A
DFAC	0.3%	$12,831	$601	$88	21 yrs
COF	24.8%	$168,065	$24,633	$353,403	7 yrs
TEMF	21.8%	$47,217	$5,657	$72,733	8 yrs

In fact, Fort Carson is already achieving envelope energy savings well above code levels. These findings indicate how to maximize those gains through the use of the most optimal envelope packages for each building type. (Discrepancies are discussed below.)

Finding 2: Results vary widely by building type: e.g., envelope improvements are a key component of NZE design for buildings with large heating loads, but may be less helpful for buildings that are dominated by equipment loads.

This study confirmed and quantified the value of using envelope packages that are adapted to the unique attributes and usage patterns of each building type.

First, the research team found the five building types to have very different heating requirements—a fact that drove many of the subsequent results. Whereas the COF and TEMF use 60–64% of their energy on heat, the DFAC and Barracks use 29–39%, and the HQ building only 2%. Both the HQ and DFAC generate much internal heat, from the data center and cooking equipment, respectively.

As shown in Table 23, the buildings with higher heating needs benefited most from envelope improvements beyond code, showing large, lifecycle cost-effective whole-building energy savings with significant net present value (NPV) and simple payback within 7–10 years. By contrast, for the buildings that generated more of their own internal heat, reducing heat losses through the thermal envelope was often counter-productive, increasing cooling energy requirements more than it reduced heating energy needs.

As another example of divergent findings among building types, semi-conditioned spaces (e.g., storage sections of the COFs and open bay areas of the TEMFs) did not appear to benefit from envelope upgrades as much as fully conditioned spaces.

Finding 3: Thermal zoning and ventilation setback when troops are deployed can yield energy savings up to 23%.

As shown in Table 24, zoning to shut off HVAC services to parts of buildings during troop deployment appeared to be a high energy and cost saving measure in buildings with large heating loads (Barracks, COF, TEMF). This was true even though the analysis conservatively included only the effects of reduced ventilation and relaxed thermostat settings, without estimating reductions in lighting and plug loads. Again, the impact in the low heating load HQ and DFAC buildings was more modest.

Table 24 Impact of Relaxed Thermostat Settings and Reduced Ventilation Rates During Troop Deployments

Building Type	Annual Cost Savings	Annual Energy Savings
Barracks	$12,508	14%
HQ	$2,955	4%
DFAC	$7,799	4%
COF	$25,047	23%
TEMF	$5,254	12%

While this analysis was specifically targeted at new construction of specific Fort Carson building types in the Colorado Springs climate zone, based on best available cost estimates, it may be replicated for other building types, climates and cost structures.

Daylighting and Lighting System Performance

This study sought to evaluate the performance of the lighting and daylighting systems in four Fort Carson building types, to determine their levels of efficiency, ability to meet occupant needs, and potential for improvement to NZE levels.

The research team's findings therefore include information on Fort Carson's current lighting and daylighting performance, and recommendations to enhance performance to levels sufficient to support the base's NZE installation goal.

Finding 1: Fort Carson is using up to 50% less lighting energy than code level buildings.

The space surveys showed that Fort Carson's lighting systems are well designed and implemented, and meet most of the research team's qualitative NZE criteria, including:

- façade design that brings in sufficient daylight,
- minimal glazing-to-surface-area ratios,
- reducing glare and maintaining occupants' visual comfort, and
- integrating daylighting with lighting controls and other building systems.

As a result, buildings studied at Fort Carson (including HQ, TEMF, COF, and office buildings) are using a lower percentage of their energy on lighting than comparable buildings designed to meet ASHRAE Standard 90.1-2007. While commercial buildings typically use 30–40% of their energy on lighting, the HQ building in the study is only using 15% of its energy on lighting, and the retrofitted office building only 22%. The lower lighting energy use in the study buildings is likely due to a number of practices, including:

- *Electric lighting reductions,* such as using more efficient fluorescent and Light Emitting Diode (LED) fixtures;
- *Daylighting features* including bringing in high daylight with diffusing apertures, clerestories, and skylights;
- *Lighting controls,* such as occupancy sensors (automatic on and off) and vacancy sensors (manual on, automatic off); and
- *Occupant engagement activities,* such as “Please turn off the lights” stickers.

Based on the research team’s measurements, Fort Carson is generally successful at aligning lighting status with occupancy, i.e., lights are mostly off when spaces are unoccupied.

Finding 2: The base has further opportunities to optimize lighting quality and efficiency while reducing consumption to levels 90% lower than required by code.

While Fort Carson is doing an above average job on lighting and daylighting, the research team identified several areas for further improvement to boost performance to NZE levels. These include:

- Optimizing daylighting design features, such as louvered overhangs and transom glass, to maximize daylighting gains.

- Increasing application of blinds and controls to use daylight effectively.

- Reducing the unnecessarily high light levels to which fixtures are set, so that even high-efficiency LED lights can save more energy than they do currently.

- Replacing occupancy sensors (automatic on and off) with vacancy sensors (manual on, automatic off), i.e., making the off position the default until manually adjusted, to reduce the amount of time lights may be left on unnecessarily.

From a strategic perspective, based on NREL's experience, lighting systems typically should consume no more than 10% of total building energy load to meet NZE targets. This translates to about 75% lighting energy use reduction from the code baseline (ASHRAE Standard 90.1-2007), which in turn breaks down into expectations of 50% savings in non-daylit areas and up to 90% in daylit spaces.

Following these expectations and NREL's observations and measurements at Fort Carson, the research team proposed a comprehensive lighting strategy to work toward NZE goals:

- Set a 75% energy savings goal and translate that into a lighting energy use intensity goal. Require the lighting designer and commissioning agent to verify that essential steps toward the goal are being met.

- Set ambient light at minimum acceptable levels to meet occupant needs (e.g., 25–30 fc (269–323 lux) for working spaces, potentially lower for other space uses).

- Provide glare-free daylight in all spaces, as the baseline source of ambient light.

- Design exterior overhangs (for south and west sides) and blinds to carefully refine the split between the upper portions of windows used for daylighting and the lower portion used for views. Use transom glass at the inner wall of most perimeter spaces.

- Use low partition heights and light interior surface color to reflect light and create bright vertical surfaces.

- Design in layers of light to allow occupants additional choices, such as task lighting, to meet their individual needs.

- Engage occupants and design user-friendly control systems to meet their needs.

- Use vacancy sensors rather than occupancy sensors in most settings, so occupants need to “opt-in” for light beyond ambient levels.

- Zone electric light systems to tailor them to the space (e.g., to take advantage of perimeter daylight) and to occupant preferences.

- Consider a central lighting control system with consistent, intuitive controls to assist facility managers with continuity of operations, re-commissioning and ease of use.

Net Zero Retrofit Optimization

The net zero retrofit optimization study was designed to:

- Identify a lifecycle cost effective pathway to achieve energy reduction performance up to NZE for an office retrofit project, and

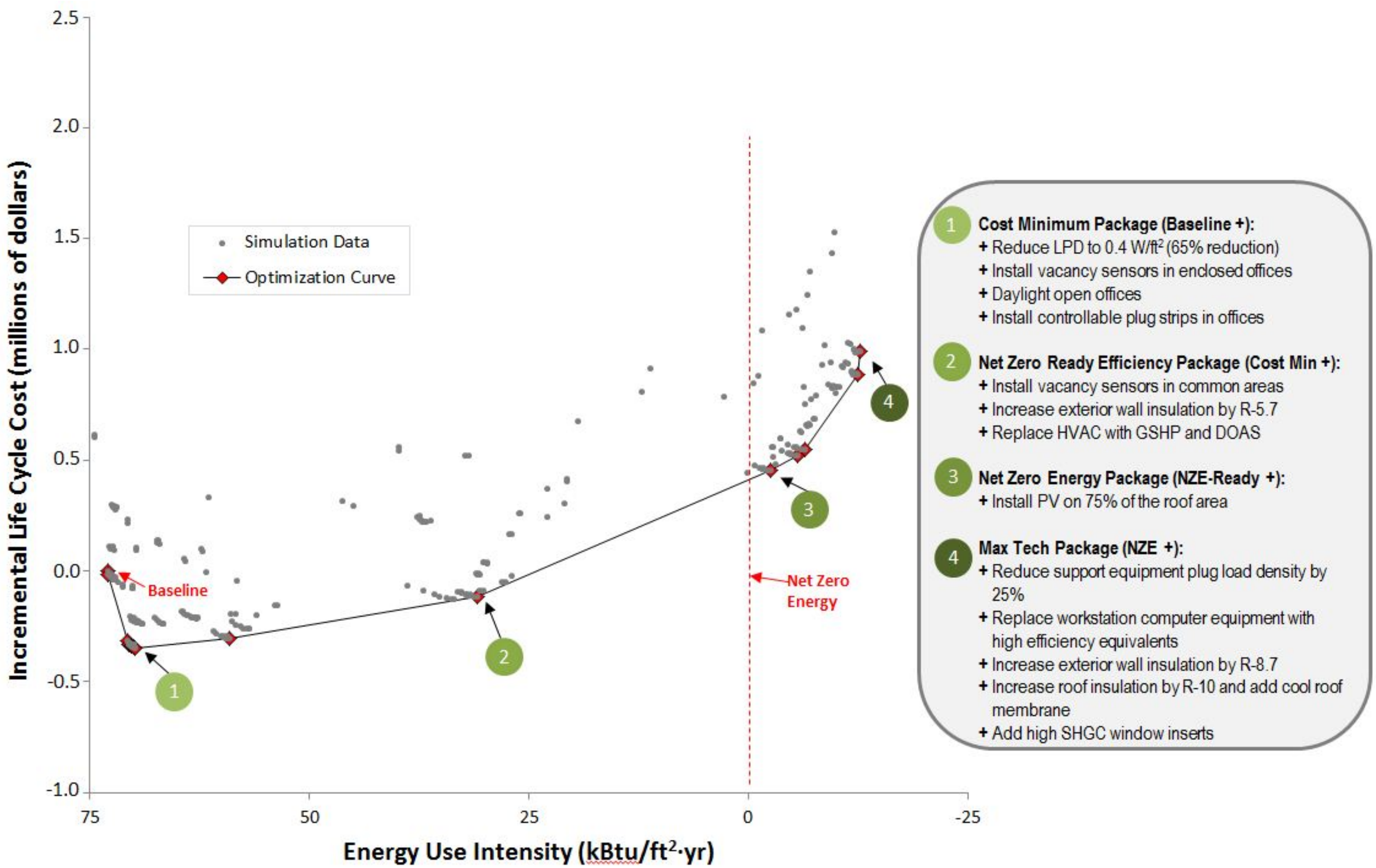
- Demonstrate the feasibility of using open source, on-line modeling tools for NZE energy retrofit planning.

NREL developed a list of best practices for energy retrofit and modeled them, based on energy savings and lifecycle costs, for an office building that had been renovated from a former barracks,. Lifecycle cost estimates factored in first costs, energy cost savings, maintenance costs, replacement costs and discount rate over a 20-year period.

This approach yielded findings regarding both the most beneficial combinations of methods and technologies to achieve cost-effective energy efficiency in a retrofit project ("technology bundles"), and the usefulness and replicability of the methodology and results.

Finding 1: Fort Carson office building retrofits have a clear, low-risk investment path of bundled energy technology solutions from lowest life-cycle cost to NZE

NREL's simulation created a roadmap (Figure 71) showing a logical progression for investments to be steadily ramped up, starting with the most lifecycle cost effective technology bundle on the bottom left, with the return on investment steadily decreasing as the line moves upward, toward the ultimate goal of NZE. Table 25 summarizes the impact of applying these approaches, as each bundle incrementally boosts energy savings.



Note: DOAS – dedicated outdoor air system, GSHP – Ground source heat pump, HVAC – heating, ventilation, and air conditioning, kBtu/ft2•yr – thousand British thermal units per square foot per year, LPD – Lighting Power Density, PV – Photovoltaic, SHGC – Solar heat gain coefficient, W/ft2 – watts per square foot

Figure 71 Retrofit Optimization Results: Energy Model Simulation Output

Table 25 Summary of Retrofit Optimization Results

Technology Packages	Energy Use Index (EUI/Net EUI: kBtu/ft^2 yr)	Net Energy Savings (%)	Incremental Total Lifecycle Cost (millions of $, over 20 years)
Baseline	73.0	NA	NA
Cost Min	69.9	4%	-0.3
NZE Ready	30.9	58%	-0.1
NZE	30.9/-2.5	103%	0.5
Max Tech	20.7/-12.7	117%	1.0

Bundled technology packages along this roadmap include:

- **Cost Minimum Package:** This technology bundle (including reducing lighting power density 65%, installing vacancy sensors in enclosed offices, daylighting open offices and using controllable power strips) represents the best investment dollar-for-dollar, though with modest energy savings (less than 5%).
- **Net Zero Ready Efficiency Package:** This package yields 58% additional energy savings, slashing the energy use index (EUI) to 31 kBtu/ft^2/yr and making the building "net zero ready," i.e., including all efficiency measures more lifecycle-cost-effective than adding renewables. Efficiency measures include installing ground source heat pumps, dedicated outdoor air systems, vacancy sensors in common areas, and added exterior wall insulation.
- **Net Zero Energy Package:** This package adds renewable energy sources on top of the previous packages, to the point that NZE performance is attained.
- **Max Tech Package:** The most aggressive—though least cost-effective—efficiency package without renewables included. Measures include maximizing insulation levels and installing high efficiency equipment.

Finding 2: Publicly available open source tools can be used to identify much of this roadmap of bundled energy technology solutions.

The Fort Carson net zero retrofit optimization analysis was focused not simply on obtaining the simulation results but on defining an effective, straightforward, and replicable process for others to use. Accordingly, the research team utilized only publicly available modeling tools including OpenStudio (http://openstudio.nrel.gov), SketchUp (http://www.sketchup.com), and Match Photo (http://help.sketchup.com/en/article/94920). The process was found to be generally replicable, with a few tips and caveats:

- While OpenStudio continues to make progress in improving the scope and usability of its tools, they did not completely cover the needs of this research study. The definition of energy efficiency measures and sequential search optimization as part of this project's energy modeling analysis still required a significant computer scripting component. For projects in which more simplified models would be acceptable, this barrier can be mitigated by using default inputs rather than project-specific variables. NREL's Building Component Library (BCL) (https://bcl.nrel.gov) can be used as a source of such default components and measures. In fact, while this study involved modeling a building in great detail to demonstrate simulation tool capabilities, a user could save a great deal of time and effort by simplifying the model without significantly reducing its accuracy.

- This project used Match Photo to capture the geometry of a building with the use of photos. However, where other building data are available, a model can be constructed much more simply and quickly from documented dimensions.

Although this analysis was geared to one specific building retrofit project, this lifecycle based, integrated design approach to efficiency package selection may be applied more broadly.

Occupant Behavior

For the occupant behavior study, Pacific Northwest National Laboratory (PNNL) sought to:

- Better understand the energy-related behaviors of Fort Carson building occupants, and
- Apply that understanding to a research intervention, testing an evidence-based approach to spur occupants to increase energy-saving actions.

The research team gathered initial occupant data from surveys, group and individual interviews, site visits, and limited energy metering. Although a low survey response rate made it difficult to draw conclusions, the data did allow PNNL to identify two occupant behaviors to target for a behavioral research intervention: end-of-day computer shutdowns and thermostat setbacks.

The three-month intervention was carried out at five buildings (one Brigade HQ, 2 COFs, 2 office buildings), with the assistance of each buildings' Building Energy Monitor (BEM). BEMs are members of the Army building community who have been assigned responsibility to monitor building operations for energy saving opportunities and problems. The BEM program has been deployed Army-wide, although not all buildings have been assigned BEMs. Evaluating the potential of this program was a major focus of the intervention.

The intervention was designed and conducted based on a theoretical framework that identifies the rules, roles, and tools that shape the context for energy conservation behavior:[25]

- **Rules** include both formal and informal policies and procedures related to energy use, e.g., both required and traditional thermostat set points. In this project, occupants particularly needed clarification of rules about whether shutting down one's computer at the end of the day was encouraged or even permitted.
- **Roles** refer to individuals and groups with the most influence over energy use, including occupants, building managers and base commanders. For the intervention, BEMs played a key role in educating occupants on energy saving approaches, while leadership reinforced these messages by endorsing them from the top down.
- **Tools** are technologies, systems, and processes that can be used to support energy use reduction goals. In this project, researchers equipped BEMs with a suite of tools (floor check forms, posters, etc.) to enable them to play their role more effectively, while additional tools (computer scans, post-intervention surveys and interviews, metering, etc.) were used to evaluate results.

Finding 1: Occupants increased energy-saving behaviors as part of the intervention, leading to energy reductions of approximately 2% in one building. Success rates varied across the five buildings.

[25] Wolfe, A., Malone, E., Heerwagen, J. & Dion, J. (2014). *Behavioral Change and Building Performance: Strategies for Significant, Persistent, and Measurable Institutional Change.* Pacific Northwest National Laboratory. PNNL-23264. http://www.osti.gov/scitech/biblio/1132691

As shown in Figure 72, occupants of all five buildings participating in the behavioral intervention shut down a greater percentage of their computers at the end of the day, increasing on average from 13% to 51% of computers (measured from the first week of the intervention to the peak week of compliance for each building).

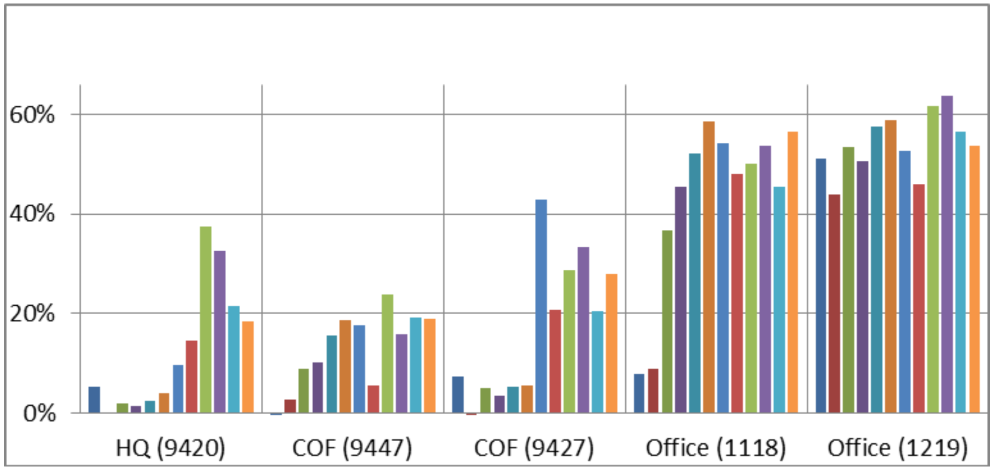


Figure 72 Percent of Computers Shut Down at Night by Building and Week Based on Computer Network Scans

This increase corresponded with post-intervention surveys showing 72% of civilian occupants reporting more frequently turning off their computers at night, and 52% more frequently shutting off their monitors. Over a quarter of respondents also reported more frequently turning off lights and setting back thermostats at the end of the day, though the research team had less data to confirm these behavior changes. (Survey results from military personnel were insufficient for analysis.)

Despite energy measurement challenges during this project, analysis of metered data from one of the office buildings studied suggests that the intervention contributed to a reduction in energy use of at least 2% after just three months. A longer intervention period may have allowed opportunities to achieve higher levels of compliance. If 100% of occupants had complied with these measures, energy savings are estimated to have ranged from 3% to 7%. While these savings may sound modest, in the context of a NZE goal, every increment of savings matters.

Finding 2: Having an engaged Building Energy Monitor (BEM), with reinforcement from leadership, helped drive behavior change.

The research team's findings suggest that a BEM-like program can work to promote energy-saving behavior change, if such a program includes certain features:

- **Revisit BEM qualifications and identify a qualified BEM for each building.** The BEM should be viewed as a specialized job function requiring specific communications skills. BEMs may be most effective if they: (1) have an interest in the position, (2) are personally committed to energy conservation and sustainability, (3) have some level of respect from the occupants (e.g., a fairly high-ranking officer in military buildings), and (4) are comfortable engaging building occupants in dialogue about energy. They should be energy coaches who aim to help occupants without being overly intrusive.

- **Create accountability and incentive structures.** In addition to ensuring that BEMs have the time to carry out their duties, supervisors of BEMs should establish clear expectations for BEM duties, ensure they are completed, and recognize and reward good performance. An expected time commitment—e.g., two hours per week once the BEM has identified building-level conservation opportunities—should be established and reinforced by supervisors.

- **Provide BEMs ongoing training on behavior change.** In addition to checking a building's physical features for possible impacts on energy performance, BEM training must also explicitly address how occupants impact energy use, and how best to influence these behaviors.

- **Provide BEMs with a toolkit that can be adapted locally.** BEMs need a set of simple, periodically updated tools to understand how the building and its occupants are performing, and to engage occupants effectively, such as:

  - Monthly building energy performance summaries,
  - A floor-check template,

  - A list of energy use behaviors commonly seen on installations,
  - A model conservation behavior-change plan, and
  - Templates for email messages and topics to address, which BEMs can tailor based on their buildings' characteristics and performance.

- **Make new occupant energy orientation a requirement.** New occupants should receive a personal, brief and timely building orientation. For example, for buildings with occupant control of heating/cooling units, the BEM might establish expectations for thermostat setbacks.

- **Regularly measure and provide feedback on performance.** BEMs should provide regular feedback to occupants on building energy performance and the impact of specific behaviors on energy use. This will require setting up energy meters and systems to make these data readily accessible and developing analytics to make the data informative.

Finding 3: Occupant behavior can be influenced as part of a well-structured effort that includes considering the institutional context, targeting specific and relevant behaviors, providing social reinforcement, measuring results, and incorporating feedback.

This study reinforced previous behavioral research findings in demonstrating both the challenges to and opportunities for influencing occupant energy behavior. As people have many competing demands on their time, simply getting their attention, much less their commitment, can be difficult in many environments. Occupant behavior change should not be the first or only strategy employed for energy reduction in buildings, but should be part of an integrated strategy that includes optimizing building systems and setting default conditions that favor energy conservation.

Figure 73 Office thermostat

Nevertheless, given that the human element will always be a factor in building operations, and that much energy behavior is habitual, influencing occupant energy habits can provide significant benefits.

Key lessons for employing occupant behavior strategies include:

- **Understand the institutional context in which behavior takes place.** While individual behavior is important for energy reduction, many institutional factors can reinforce or inhibit individual action. The harmonization of policies (rules), communicators (roles) and approaches (tools) involves considerable coordination by change agents to ensure that desired behaviors are enabled by appropriate policies, and communicated and reinforced by trusted authorities. Building energy programs should work to identify and eliminate institutional barriers and provide guidance and resources to building-level change agents to get rules, roles, and tools successfully aligned.

- **Make desired behaviors specific and relevant.** Energy programs often employ broad-based awareness programs coupled with generic lists of the "top ten things" occupants can do to save energy. While education and awareness are essential, simply providing information and calling attention to it are often insufficient to elicit sustained behavior change. The more tailored the advice is to one's specific circumstance, the more relevant it is likely to appear to its target audience.

- **Provide social reinforcement through known, trusted sources on a regular basis.** Institutional and behavioral change should be regarded as a *high touch* activity, reinforced through person-to-person interaction, rather than simply a *high tech* activity. This includes having advocates for energy conservation at the local or building level who can observe behavior and engage in dialogue with occupants. It also includes reinforcement from leadership figures.

- **Measure results and provide regular information and feedback on performance.** Achieving all of the goals outlined above requires an iterative process whereby occupants both give and receive feedback. Program success requires taking into account occupant concerns, ideas and levels of comfort and productivity. It also requires providing information on energy performance to occupants, energy advocates, building managers and leaders so that all can know where they stand and adjust behaviors and systems accordingly. Energy metering and submetering are important wherever practical to gauge progress and areas for improvement.

Recommendations Based on Research Findings

The Fort Carson Energy Research Project examined a series of strategies to help already above-average green buildings approach NZE levels—all within the constraints of an active military base. While the findings of this project are specific to the building types, systems, climate and population of Fort Carson, they also reveal lessons in integrating energy efficiency strategies applicable to other buildings:

- The building systems research conducted under this project demonstrated the value of taking a deep dive into how efficiently building systems (like lighting and envelope) are operating and identifying opportunities for improvements, up to NZE. Analyses that take lifecycle costs and benefits into account lay the groundwork for making the most rational decisions over the lifetime of a building.[26]

- Best practices identified should be built into portfolio planning, standards, contract language and specifications. Solutions will need to be adapted to each individual building, at which point technologies and approaches can be bundled together to form the most lifecycle-cost-effective progression of investments.

- The behavioral research demonstrated opportunities to effectively engage building occupants in energy reduction. The research suggested the value of integrating building systems improvements with occupant engagement strategies, as both are needed to achieve NZE levels.

[26] Note that it would not be accurate to simply add up the savings among the studies represented here, due to methodological variations and potential double-counting among them.

- Engaging occupants requires employing institutional approaches that integrate changes in policy and organizational roles with programs to influence specific occupant behaviors. Occupants need support to adopt energy-saving behaviors, and all relevant rules, roles and tools should be considered and adjusted to ensure that they receive such support. As a key example, local energy advocates need systems to monitor energy use and gain feedback from occupants while also informing occupants of energy use levels and how they can reduce them.

Attaining a high standard like NZE requires finding and using every tool in the toolbox. Yet even such an ambitious goal appears increasingly attainable as building professionals learn how to design and adapt building systems and work with occupants to make it happen.

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