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COUPLING DEMAND RESPONSE AND PDCA TO LEAN BUILDING OPERATIONS: A PROOF-OF-CONCEPT

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ABSTRACT

The Plan-Do-Check-Act (PDCA) approach allows stakeholders to identify potential changes and measure their impacts on a small scale prior to making a larger investment in such a change. One change that could be evaluated through PDCA is the installation or implementation of energy efficiency measures (EEMs). Building owners may be reticent to implement energy efficiency measures (EEMs) without fully understanding their costs and benefits. A PDCA approach coupled with demand response (DR) – whereby building owners reduce electricity consumption during periods of peak electricity demand in exchange for incentive payments – allows owners to assess EEM performance in a pilot study prior to making a larger investment in the EEM. Various EEMs can help building owners and operators shift their energy consumption to off-peak hours to earn DR incentives, e.g., reducing lighting power via controls, precooling a building prior to the peak hours. This paper documents how one building owner, Arizona State University, leveraged PDCA to identify DR strategies for a campus building and then used results from the DR event to identify permanent EEMs for the building. This case study serves as a proof of concept that indicates that a PDCA approach that leverages DR implementation supports identification of EEMs for permanent installation.

KEYWORDS

PDCA, energy management, lean operations.

INTRODUCTION

This paper crosswalks the lean concept of PDCA with energy management. This paper explores, through case study, how participation in a Demand Response (DR) program can serve as a first run study and inform future energy management efforts in a building.

PLAN DO CHECK ACT (PDCA)

Shewhart (1939) and Deming (1986; 2000) discuss the plan-do-check-act (PDCA) cycle that supports continuous process improvement. In the buildings industry, this cycle can be implemented in support of lean design, construction, and operations processes. Implementation of PDCA for improving the building design and construction process is well-documented (e.g., (Hassan 2006; Sobek II and Smalley 2008; Parrish et al. 2009; Zhichun and Yuejun 2011). In the operations phase, research documents how PDCA can be used to improve work processes, not necessarily to improve energy performance (Smith and Hawkins 2004; Ishikawa et al. 2012). Literature also documents how PDCA can be used to reduce building energy consumption (ISO

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2011; Parrish et al. 2012; Parrish and Whelton 2013). In this paper, we explore how participation in DR programs serves as a first run of PDCA for energy management, through the application of PDCA on a case study project.

DEMAND RESPONSE

Demand Response (DR) is generally defined as a measure to decrease energy demand in a building to alleviate the strain on the grid during peak hours (FERC 2019). DR programs involve a contractual commitment for demand reduction and agree to an incentive payment for said reduction (Motegi et al. 2007). Utility providers often activate their DR programs, or call a DR event, to manage demand based on forecasted energy prices and weather (Henríquez et al. 2018; Abapour et al. 2020; Gerke et al. 2020; Liu et al. 2022). DR supports reliability in that it can reduce demand, in turn reducing the need for brownouts or blackouts within the utility service territory. Weather forecasting allows for reasonable prediction of the demand and also allows utilities to determine the value of demand reduction (i.e., if DR incentive payments [$/kWh avoided] to customers are the most cost-effective means of reducing demand on a given day). Customers opt in or out of a DR event and then reduce their demand in accordance with the commitments outlined in the agreement with the utility. In some cases, customers implement DR strategies in house, while in other cases, an outside contractor will implement building controls to achieve load reduction during an event. For example, a building owner precool a building to reduce the need for air conditioning, and therefore, reduce energy demand, during a DR event. To do so, an owern may set their thermostats to temperatures below comfort levels prior to the period of peak demand, and then allow the temperature to “float” to a temperature at the high end of the comfortable range during the DR event (e.g., (Yin et al. 2010; Sun et al. 2012; Arababadi and Parrish 2016; Arababadi et al. 2017; Arababadi and Parrish 2017). According to Gerke et al., approximately 9% of commercial buildings in the United States participated in DR programs as of 2018 (2020).

RESEARCH OBJECTIVE

The authors’ objective is to develop a PDCA process that leverages DR to support assessment of DR strategies for permanent EEM installation. This is paper documents such a process and presents results from an implementation at Arizona State University (ASU).

LITERATURE REVIEW

Literature (Assimakopoulos et al. 2020; Moran et al. 2020; Qu et al. 2020; Rau et al. 2020; Uidhir et al. 2020; Coyne and Denny 2021; Li et al. 2021) supports that addressing energy management holistically, e.g., through implementation of a certified energy management system (ISO 2011; Parrish and Whelton 2013), is a best practice. Indeed, Moran et al. (2020) discuss the benefits of coupling building envelope retrofits with heating system retrofits. This allows building owners to reduce their heating demand (through increasing insulation in the envelope) and install a smaller heating system when they replace their original heating system with a heat pump. Similarly, Li et al. (2021) discuss the ability to reduce the air conditioning load in a school building when daylighting is used in lieu of artificial lighting – the need for air conditioning decreases due to the fact that the daylighting does not generate as much heat as the artificial light. Finally, Qu et al. (2020) discuss the energy and carbon reduction benefits of coupling passive and active energy efficiency measures with renewable energy production in Norwegian apartment buildings; their work illustrates that a holistic approach yields 66% more savings than an approach that only installs passive efficiency measures.

While a holistic approach that leverages the synergies between building systems is effective, this approach may represent too significant of an investment for many building owners or operators, who may not be able to justify the capital expense of EEM implementation without knowing how the EEM(s) will perform in their particular building and in their particular climate. PDCA allows building owners and operators to first test EEM performance prior to investing in the EEM installation throughout the building, using the DR event as the "Do" phase of the PDCA cycle and evaluating EEM performance through the "Check" phase prior to implementing the EEM in the building in the "Act" phase. Given that DR participation involves an incentive payment, leveraging PDCA to identify DR (and subsequent EEM) strategies and their performance represents a lower-cost opportunity for owners to reduce energy consumption.

METHODS

This research began by documenting how the PDCA process could be used to identify DR strategies, as well as for evaluating their implementation. To assess whether this proposed process would be feasible, the authors conducted an interview with the energy manager responsible for implementing DR at Arizona State University to determine whether a PDCA approach could be used to identify and evaluate DR opportunities on campus. Finally, the authors present energy data from DR implementation to serve as a proof of concept and illustrate the efficacy of using PDCA to identify DR strategies and evaluate whether these strategies show promise for EEM implementation throughout the building(s).

Development of PDCA Approach that Leverages DR

The authors began with the PDCA process and added DR implementation to it as a proposed process for identifying EEMs, where DR implementation serves as a first run study.

Interview Protocol

The authors developed the interview protocol (Table 1) to assess the feasibility of implementing the proposed PDCA process at ASU. As such, the questions focus on whether or not, and how, ASU currently completes PDCA to identify DR strategies (questions 1 and 2). The authors also sought to understand how ASU's DR participation impacted the selection of EEMs for campus buildings (questions 3 and 4). The authors conducted the interview in November 2022 with the energy manager responsible for DR implementation on ASU's Polytechnic campus; he has over 20 years of experience in facilities and energy management in higher education. Given that this paper documents a proof-of-concept for a single building owner, the authors interviewed the one energy manager that makes decisions about DR and EEM implementation on the campus. The authors did not code the interview responses, as three of the four questions had straightforward responses. Question 2 asked the energy manager to share a process, this was documented by the authors as the interviewee described it.

Table 1: Interview Protocol

Question	Response Options
How much load do you commit to DR?	kW committed
How do you currently determine strategies to implement to achieve load shift or shed during a DR event?	Process for selecting DR strategies
Do results of DR implementation help to identify potential investments in long-term energy efficiency measures?	Yes or No
Do you consider permanently implementing the successful DR strategies for sustained energy savings?	Yes or No

RESULTS

PROPOSED PDCA APPROACH FOR SELECTING EEMS BASED ON DR RESULTS

Figure 1 documents the proposed PDCA approach for selecting EEMs based on DR implementation.

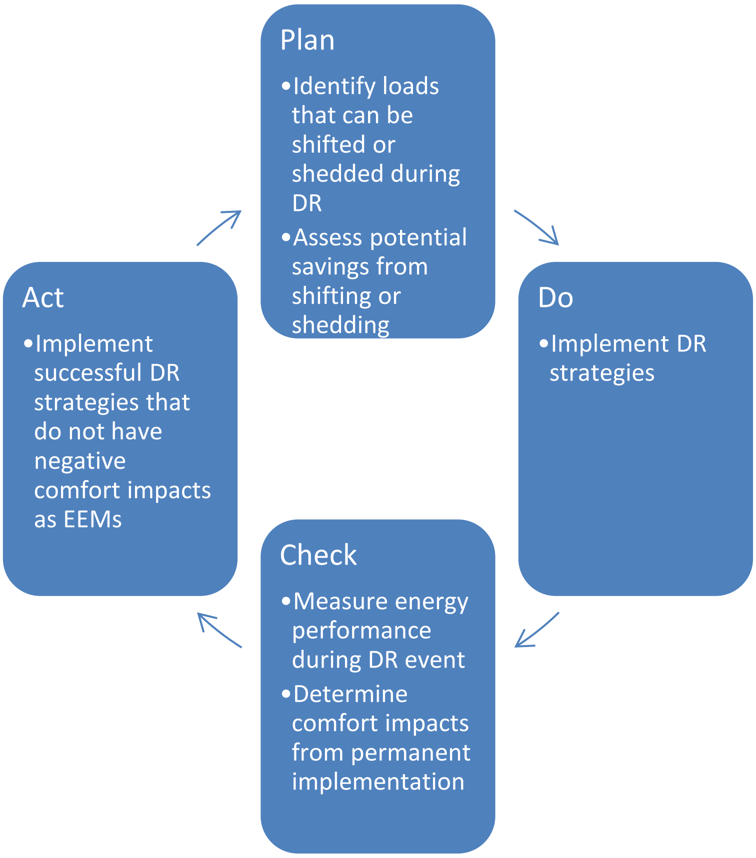

Figure 1: Proposed PDCA Approach for Selecting EEMs based on DR Implementation

The Plan phase requires that energy managers consider the energy consumption and demand of their building(s) and identify loads that may be able to be shifted, e.g., through precooling a facility (Yin et al. 2010) or shed, e.g., turning lights off, during a DR event. The Plan phase also requires that the energy manager estimate the potential reduction in demand to ensure that the DR strategies being considered provide sufficient demand reduction to secure the incentive payment associated with the DR program. During this phase, the energy manager(s) may generate several alternative DR strategies that satisfy the demand reduction commitment; if this is the case, the authors suggest using Choosing by Advantages, or CBA (Suhr 1999; Parrish and Tommelein 2009; Arroyo et al. 2015), to select the most advantageous set of DR measures to implement during a DR event.

The Do phase is when energy managers implement DR strategies, either via building controls or through manually adjusting building operations.

The Check phase requires energy managers review the impact of the DR strategies on demand reduction and energy consumption. At this stage, energy managers also need to evaluate whether DR strategies led to increased complaints from building occupants about thermal or visual comfort. For example, did occupants complain that the building was too hot or too cold during the DR event?

Finally, the Act phase requires energy managers determine which DR strategies have most promise for permanent implementation as EEMs. Research documents several examples where building owners and operators have implemented DR strategies on a permanent basis to realize those energy savings consistently (Mathieu et al. 2013; Arababadi et al. 2017).

INTERVIEW RESULTS

Following the implementation of DR strategies in the summer of 2022, the authors interviewed the energy manager at ASU to determine whether the proposed process (Figure 1) would be a viable approach for ASU to identify EEMs. The energy manager indicated that a formalized process for permanently implementing successful DR strategies would be helpful. Further, they indicated that, to date, the review of DR implementation was generally done to determine what DR strategies would be repeated in the future without considering which DR strategies may be strong candidates for permanent installation as EEMs.

PROOF OF CONCEPT: ASU ENERGY DATA REVIEW

Plan

In 2020, ASU participated in a DR program for the first time. To prepare, the campus energy manager reviewed energy consumption across campus in the campus' energy information system (Figure 2) and took the following approach during the "Plan" phase:

1. Review the metered electrical usage data for campus buildings and identify anything with at least one 15-minute demand interval larger than 500kW, i.e., the campus' largest loads.
2. Look for buildings that had at least one 15-minute demand interval larger than 150kW, i.e., medium-sized loads.
3. Examine the total kW and kWh of the buildings with "large" demand (those from Step 1) or "medium" demand (those from Step 2) over the course of the previous fiscal year to create a list of candidates based on the percentage of demand intervals that were over the targets listed above.
4. Work with the campus Facilities Management team to discuss recommendations and refine the list based on "boots on the ground" knowledge.
5. Finalize the list of buildings for participation in the DR program.

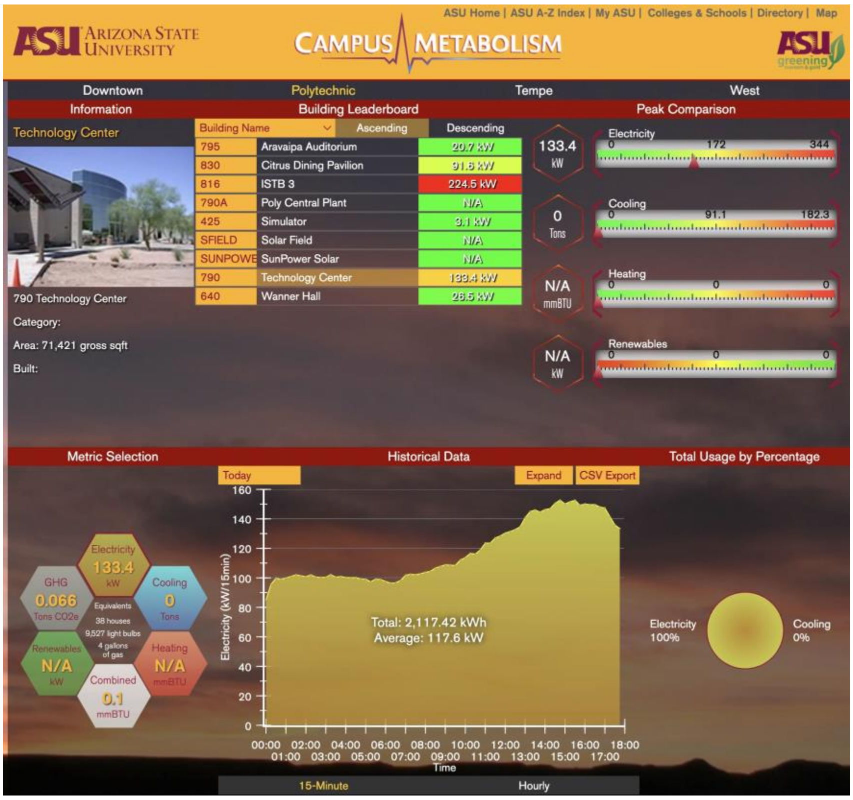

Figure 2: ASU's Energy Information System, Campus Metabolism, helps to identify buildings that may be good candidates for DR (screenshot from K. Parrish on 17 April 2024)

Once the list of buildings was finalized, the campus energy management team worked to identify specific measures to take in each of the facilities to reduce demand. They considered "typical" DR strategies like dimming lights and changing temperature setpoints (Gerke et al. 2020). Unfortunately, due to the operating requirements for classrooms and offices on campus (ASU 2024), these 'traditional' DR strategies were not feasible for ASU. Thus, the Facilities Management and Energy Management teams worked to identify customized DR strategies, including changing fan operations, increasing the temperature in the book storage facility, and dimming the lights at the Fitness Centre. The variables considered when evaluating potential DR strategies were demand reduction, in kW, where more reduction was preferred, and human comfort, where more comfort was also preferred. The energy management team avoided any DR strategies that violated ASU's operating requirements for classrooms and offices on campus, which limited their number of feasible DR strategies such that leveraging multi-criteria decision-making was not required. In fact, the energy management team initially struggled to develop feasible DR strategies that would yield the demand reductions necessary to earn the incentive payments.

Do

During the summer of 2020, ASU implemented the strategies outlined above in fifteen (15) buildings measured in eleven (11) meters and saved ~620kW per DR event.

Check

Following the implementation in the summer of 2020, the campus energy and facilities teams reviewed their success in the DR program to determine how they could increase their DR commitment in the summer of 2021, thereby increasing their incentive payment. They determined that several DR strategies implemented negatively impacted occupant comfort. For example, when classroom temperatures were set to 25.5C (the high end of the allowable operating temperature range in classrooms) during the summer at 15:00 (the start of the DR event), the classrooms quickly became uncomfortable as students released sensible and latent heat when they entered the classroom warm from an outdoor walk (outdoor temperatures in Arizona are approximately 40C during DR events). Thus, strategies that increased classroom temperatures were determined unfit for future DR seasons.

The energy and facilities teams also identified DR strategies that showed promise for future implementation, including shutting down the air handler to the book storage facility, which had sufficient thermal mass to maintain safe temperatures throughout the three-hour DR event, even when the air conditioning to the facility was shut off. Similarly, the light dimming in unoccupied areas of the Student Fitness Centre showed promise for future implementation.

Act

In 2020, this phase consisted of documenting the DR strategies that could be implemented in future DR events, in 2021 and thereafter. Indeed, reflecting on the successes and challenges associated with DR implementation provided valuable insights for future DR enrolment. By 2023, ASU had increased its DR commitment to over 1MW, and was able to secure increasing incentive payments each year.

In 2022, the authors presented the Energy Manager with the proposed PDCA approach for selecting EEMs. At this point, the conversation following DR implementation expanded to include an agenda item for identifying DR strategies that could be permanently implemented, i.e., those strategies that could serve as EEMs rather than simply DR strategies. The energy and facilities teams highlighted that the automated light dimming in unoccupied areas of the gym was a strategy they would like to implement year-round. The teams also identified other DR strategies they would consider as EEMs, like precooling classrooms and automated light dimming across campus. Importantly, the teams also highlighted those DR strategies that could not be permanently implemented, like shutting down the air handler that served the book storage facility.

DISCUSSION AND RECOMMENDATIONS

The authors discuss herein how the PDCA approach described above can support identification of potential EEMs, thereby reducing the investment cost and minimizing the risk that the EEM does not yield the expected energy savings.

EVALUATING ALTERNATIVE DR STRATEGIES IN THE "PLAN" PHASE

At ASU, the set of feasible DR strategies was limited due to the campus' strict operating guidelines for classrooms and offices. The operating guidelines made light dimming and temperature setpoint adjustments greater than 2.25C infeasible. However, other commercial building owners and operators may find that they have a large set of feasible DR strategies that they can evaluate during the "Plan" phase. When owners and operators are faced with large sets of feasible alternatives, the authors suggest using CBA to select from among alternatives. As at ASU, the factors to consider when evaluating potential DR strategies would be demand reduction, in kW, where more reduction is preferred, and human comfort, where more comfort is also preferred. Building owners and operators will also need to explicitly state 'must' criteria for CBA, e.g., "The building must provide light and conditioned air that supports productive work throughout the DR event" that ensure that DR strategies do not render the building uncomfortable or impossible to work in.

LEVERAGING THE ACT PHASE TO IDENTIFY EEMS

While ASU did not refer to their DR commitment process as a PDCA effort, their process was essentially a PDCA process, even prior to the authors' engagement with the energy management and facilities management teams. Indeed, the teams had a standardized process for planning, doing, and checking. The teams used that knowledge to act on future DR commitments. The authors' engagement in this process added a new dimension to the "Act" phase, whereby the teams identified DR strategies that could be implemented permanently alongside those that showed promise for future years' DR events. While this change was relatively small for ASU, the entire process (Figure 1) may be unfamiliar to other building owners or operators. Thus, the authors recommend that all building owners and operators consider implementing PDCA to identify DR strategies and then explicitly identify the subset of DR strategies that show promise as EEMs during the Act phase.

CONTINUOUSLY IMPROVE THE "CHECK" PHASE TO SUPPORT EEM SELECTION

EEMs perform differently in different environments. For example, at ASU, light dimming yielded savings in the Fitness Centre, but not in the classrooms due to differing occupancy patterns. The "check" phase of the proposed PDCA process offers an opportunity to align evaluation criteria to evolving goals. For instance, building owners and operators may want to add criteria about consistency of energy savings during DR events to their reviews; this way, prior to investing in a permanent installation, owners and operators can be assured they will achieve the savings they expect. (Typically, energy savings for EEMs are determined via spreadsheet calculation for technology changes like ballast replacements or via energy modelling for, e.g., new building control sequences.)

Building owners and operators may consider a set-based design approach (e.g., (Ward et al. 1995; Sobek et al. 1999; Rekuc 2005; Parrish et al. 2007; Parrish et al. 2008a; Parrish et al. 2008b; Parrish 2009) when selecting potential EEMs based on DR implementation. Set-based design allows project teams to consider multiple design options longer than would be typical in a point-based design scenario. For EEMs selection from the proposed PDCA process, set-based design may involve considering certain DR strategies for multiple years before deciding to implement those strategies as EEMs. This allows project teams to consider various DR strategies and explore their fitness for the building at hand and ensure that these EEMs make financial sense for the building owner and operator, given that EEMs cannot be used for collecting DR incentives once they are part of daily operations. (This is because once installed, EEMs will reduce the baseline energy demand, and DR requires reductions from **actual** demand, rather than from a baseline demand in a prior year.) Once DR strategies that could transition into EEMs are understood, project teams can make data-driven decisions about which to install permanently using Choosing By Advantages (e.g., (Suhr 1999; Parrish and Tommelein 2009; Arroyo et al. 2015). Energy demand reductions can be expressed as a 'must' or a 'want' criterion for either DR implementation or EEM installation at the owner's discretion.

BROADER CONTEXT: EXISTING BUILDING RETROFITS

This paper explores the transition from DR strategy to EEM, and how a PDCA approach could support this transition. As decarbonization and energy efficiency policies begin to be implemented (e.g., (State of California 2018; New York City 2019), building owners may need to retrofit their facilities. A PDCA approach is demonstrated to support building energy retrofits (ISO 2011; Parrish and Whelton 2013), and this paper builds on these existing processes by highlighting how DR can be used to earn money while testing potential EEMs in actual facilities.

CONCLUSIONS

This paper explored, though case study, how a PDCA approach can be implemented alongside participation in a DR program to support selection of EEMs for building energy retrofits. The authors proposed a PDCA approach and illustrated its potential via a proof-of-concept at Arizona State University. This proposed process allows building owners and operators to understand how potential EEMs will perform in their building(s) prior to investing in EEM installation. The authors discuss how PDCA, and lean tools like set-based design and Choosing By Advantages, can help building owners and operators reduce energy demand and consumption, in turn supporting decarbonization of the building sector.

The authors note that the sample size for this work is small, so this paper only illustrates a possible process for transitioning DR strategies into EEMs. Future work may present the proposed process to other higher education institutions, and other DR program participants, to evaluate the feasibility and efficacy of the proposed process in a new context. Such efforts would be welcome in future research by the IGLC community.

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