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ABSTRACT

Utilities have been experimenting with integrated demand side management (IDSM) programs since the 2000s. The potential benefits of improved program cost-effectiveness and customer engagement from combining energy efficiency (EE), demand flexibility (DF), and other distributed energy resources into an integrated customer offering have been recognized although there are several known regulatory and program administrative challenges. In addition, as buildings adopt EE measures, the baseline load profile change generally reduces the potential load that can be shed or shifted. This has been a significant technical barrier for customers and program implementers. However, it is a myth that EE always reduces DF. Load change from EE can be time-varying. Therefore, whether EE improves or reduces DF should be evaluated on an individual measure basis accounting for weather dependencies and interactions. For IDSM program design purpose, it is useful to understand how common EE features influence DF and the underlying building physics.

In this paper, we use parametric simulations of a prototype medium office building to evaluate how various EE features influence DF, measured by a “demand decrease intensity” (W/ft2) metric. These EE features cover envelope characteristics, internal loads, and airside HVAC system. The parametric analysis shows that some efficient HVAC control measures will increase DF but not the traditional building envelope, lighting, and ventilation-related efficiency measures. These findings contribute to the technical basis for achieving enhanced energy benefits by packaging appropriate HVAC control measures in IDSM program design. Program developers should further validate these results in targeted pilot projects.

Introduction

Background

Why do we need IDSM?

Utilities in California and other parts of the U.S. have been exploring Integrated Demand Side Management (IDSM) programs design since the 2000s. The potential benefits of integrating energy efficiency (EE), demand flexibility (DF), and other distributed energy resources (DERs) into packaged program design have been articulated in a couple of systematic studies (Potter et al. 2018, York et al. 2019). York et al. (2019) identified four levels at which EE and DF can be integrated in IDSM programs; the highest level being taking full advantage of the technical capabilities of EE and DF beyond simply marketing them together or reducing program administrative costs.

These studies have also identified several challenges and barriers in implementing these programs effectively as well as the opportunities associated with them. Potter et al. (2018) identified several programmatic opportunities for commercial and industrial (C&I) sector IDSM program offerings including lighting systems and controls, retro-commissioning (RCx), energy management control systems (EMS), etc. York et al. (2019) identified a few existing C&I IDSM programs or pilots which integrate EE and DF capabilities associated with HVAC systems. In addition, some utility program implementers have also contributed to the knowledge base of what has been experimented so far, program design features, challenges encountered, and lessons learned (Starr et al. 2014, Riker et al. 2014).

One significant technical barrier for customers and program implementers is the myth that EE always reduces DF. Such barrier has been documented in studies (Riker et al. 2014). While it is true that the baseline load profile change after implementing EE generally reduces the potential load that can be shed or shifted, the load change from EE can be time-varying rather than constant depending on the measure. Therefore, conceptually, some EE measures can be less contradictory to DF than others, or even complimentary to DF. Gerke et al. (2020) created a framework for evaluating when EE and DF compliment or compete with each other at both a building level and system level. Based on the above, whether EE improves or reduces DF should be evaluated on an individual measure basis accounting for weather dependencies and EE-DF interactions. Establishing such an understanding of how common EE features influence DF and the underlying building physics will help utilities and program implementers to design targeted measure packages and offerings to achieve better program cost-effectiveness.

Existing Studies on the Interactions between EE and DF

Though there are many studies that have analyzed the impact of EE or DF measures separately, limited work has focused on combining them. A recent study analyzed the combined effects of EE and DF measures on a regional power system level through simulation, and found that their designed EE+DF measure packages have the potential to reduce annual electricity use and summer peak demand for both commercial and residential buildings. But the impact from combined measures are less than the implementing measure in isolation (Langevin et al, 2021). Another recent simulation study assessed the impact of EE and DF in isolation versus in combination on the power system cost and capacity for residential and commercial buildings. They identified that controls for various end-uses and envelope efficiency upgrades can be complimentary to DR resulting in greater capacity and transmission cost savings for the utility system, while equipment measures compete against DR (Gerke et al, 2022)[1]. Several previous studies focused on residential buildings. One study modeled a community of 498 all-electric houses, and found that DF enabled by home energy management systems reduces peak load and saves on utility bills. The savings are less in homes with envelope upgrades and efficient appliances compared to the code-compliance homes (Munankarm, 2021). Another study simulated 24 houses with varying thermal mass levels and air conditioner sizes. The results show that higher thermal insulation levels reduce the peak demand reduction during DR (Jewell et al. 2014). The metrics used in these studies are mostly peak demand and annual usage. There’s a lack of event-based metrics for evaluating the load shed during DR events. Although these studies have used bottom-up simulations, the analysis scopes of these studies are mainly on the power system level. It’s worth inspecting the building-level results and explaining the physics behind them.

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[1] Utility system costs include new generation, storage, and DR investments (capacity costs); new transmission investments or upgrades (transmission costs); and fuel and operations and maintenance cost (variable costs).

Objectives

This paper explores how various EE features ("measures") influence DF through whole-building energy simulation using a prototype medium office building of ASHRAE 90.1-2004 vintage in one climate zone as an example. Specifically, the study aims to identify exceptions to the common phenomenon where EE reduces DF. Therefore, the objective is to identify example EE measures that are either neutral or complimentary to DF for further explorations. These examples could provide insights for designing measure packages for IDSM program offerings. It may also serve as a reference for customer education to overcome some of the barriers for broader adoption of IDSM (Potter, Stuart, and Cappers, 2016).

Methodology

We assessed several categories of EE measures deployed with DF strategy on commercial buildings through simulation. The iterations are completed using EnergyPlus. DOE Commercial Reference Building models are used as the base models. We focus on the 12 hottest days in a year to imitate the DR programs in the market. The "Demand Decrease Intensity (W/ ft^2)" over this time period is the main metric for comparing the DF performance across EE scenarios.

Simulation Tool and Building Models

EnergyPlus is US DOE's flagship whole-building energy modeling software. The DOE Commercial Reference Building models are developed using this. The models represent approximately 70% of the commercial buildings in the U.S. (DOE, 2011). The medium office in 3B climate (warm, dry) is the main focus of this paper. We selected the vintage of ASHRAE 90.1-2004 to better represent the existing buildings in need of retrofit.

Studied EE Features and DF Strategy

EE measures can be categorized into upgrading envelopes, optimizing internal loads, improving the efficiency of HVAC systems, and applying control strategies. Several typical measures under each category are selected in this examination. **Table 1** summarizes the EE measures and corresponding iterations. For those measures associated with numerical parameters, granular values are tested to see the sensitivity of a particular measure to the demand flexibility performance. The range of values in each scenario is designed to represent the existing building stock according to the literature review and engineering experience of our team.

Table 1. Summary of Energy Efficiency Parameters

Category	EE Feature	Parameter	Values
Envelope	Add insulation to the walls	Wall assembly R-value ($ft^2\cdot°F\cdot h/BTU$)	1,5,9,13,17,21,25
	Add insulation to the roof	Roof assembly R-value ($ft^2\cdot°F\cdot h/BTU$)	5,9,13,17,21,25,29
	Use windows with lower solar heat gain coefficient	Window SHGC	0.9, 0.7, 0.5, 0.3, 0.1

Category	EE Feature	Parameter	Values
	Apply air sealing materials/ Add air barriers	Infiltration rate (CFM/ ft^2)	1.8, 1.378, 0.956, 0.534, 0.112,
Internal Loads	Use efficient lighting fixtures	Lighting power density (W/ft^2)	1.6, 1.28, 0.95, 0.63, 0.3
	Use energy-efficient office appliances	Equipment power density (W/ft^2)	2.0,1.6,1.2,0.8,0.4
HVAC Systems	Adjust sizing factor for system sizing	System sizing factor	0.6, 0.8, 1.0, 1.2, 1.4, 1.6
	Reduce ventilation	Ventilation rate (CFM/person)	15, 20, 25, 30, 35
	Reduce the min airflow setup for VAV boxes	VAV min damper position (%)	10%, 20%, 30, 40%, 50%
	Apply supply air temperature (SAT) reset	/	No SAT reset, w/SAT reset
	Add dry-bulb differential economizer to air system	/	No economizer, w/ economizer
	Raise zone cooling setpoint	Cooling setpoint (°F)	70,72,74,76

The DF strategy deployed with the above EE measures is global temperature adjustment (GTA). That is to raise the zone temperature setpoint by 4ºF during a DR event. In our analysis, the time window is set as 2 pm to 6 pm, which is typical for traditional hot summer afternoon DR in many regions in the U.S.

Key Metrics

"Demand Decrease Intensity (W/ ft^2)" is the main metric for quantifying and comparing the amount of load shed across each EE measure. This metric is one of the primary metrics in a set of DF metrics proposed by Liu et al. (2020) to quantify the demand flexibility of commercial buildings.

$$Demand\ Decrease\ Intensity = \frac{Average\ demand\ decrease\ during\ \text{"}shed\text{"}\ period}{Building\ Floor\ Area}\ (W/ft^2)$$

The metrics of the 12 hottest days in a year are analyzed. These hottest days are typically when DR events are called.

Results

Influence of EE features on DF performance

We assessed three categories of EE measures deployed with DF strategy on medium buildings through simulation. **Figure 1** shows the ten EE measures that have a minimal or negative impact on DF.

Some EE measures hurt the DF performance because the baseline load is reduced during the shed period resulting in a decreased shed potential. These measures include using windows with lower SHGC, adding insulation to the wall or roof, using efficient lighting fixtures (lower LPD), and using energy-efficient office appliances (lower EPD).

Several other EE measures have minimal impact on DF because the measures do not impact the load in the time period we focused on. For example, the cooling load introduced by infiltration is very small in summer. On the hottest days, the economizer is disabled. Only the minimum amount of outside air is introduced for ventilation purposes only. That's why reducing the ventilation rate or applying economizers does not affect the amount of shed.

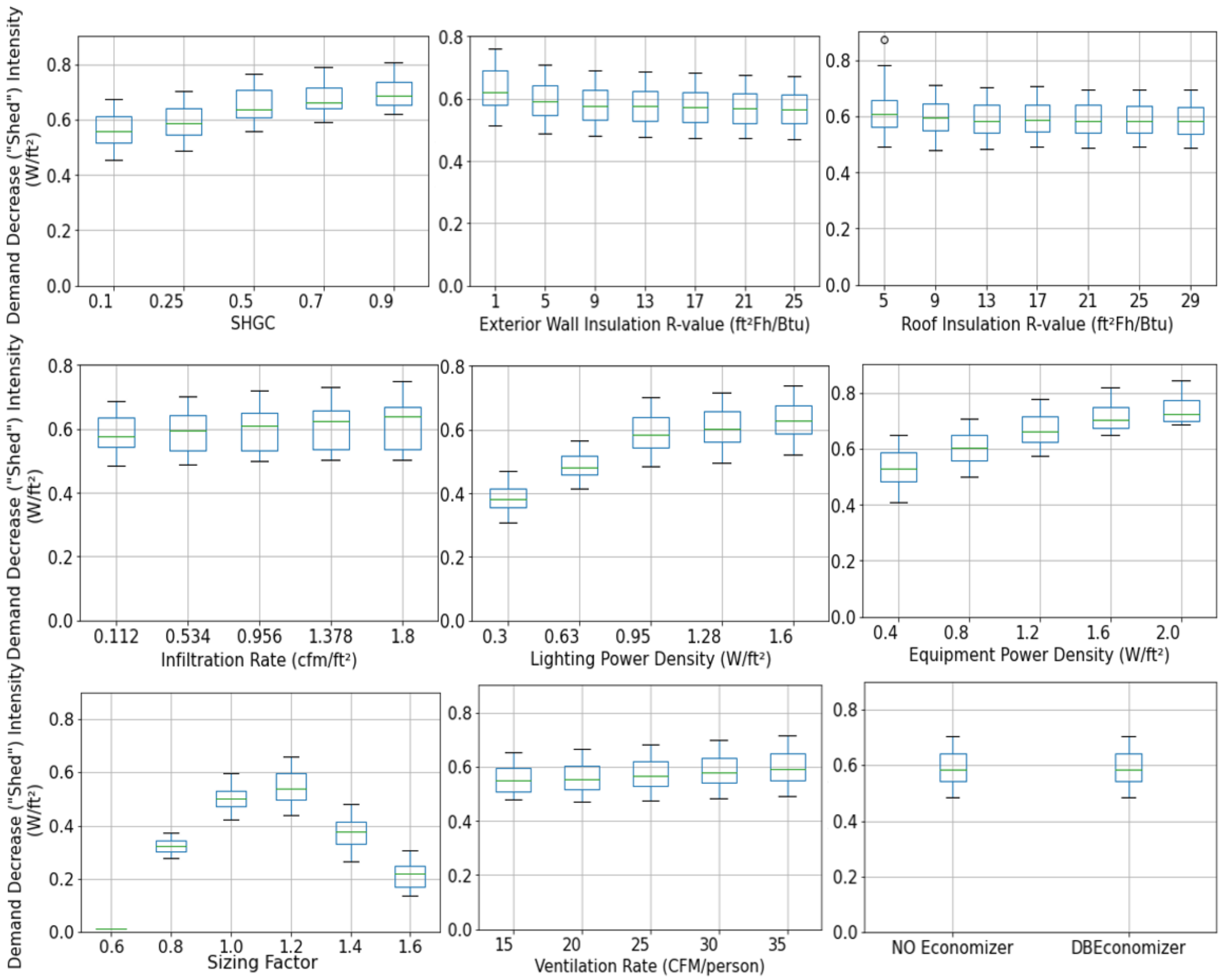

Figure 1. Demand decrease intensity change by EE measures

EE features that compliment DF performance

Among the 12 EE measures included in this study, three measures have positive impact on the Demand Decrease Intensity metric and therefore worth further analysis.

Reduce the VAV minimum airflow. ASHRAE Handbook-Fundamentals and diffuser manufacturers have suggested 30%~50% for VAV minimum airflow for many years (Paliaga, 2019). Many studies have proposed to lower the current 30% minimum limit setup for VAV damper position in the standards and codes considering the energy waste. A simulation study found that lowering the minimum airflow from 50% to ~10% can reduce HVAC energy use by 10%~30% (Hoyt, 2015). Their latest field study (Paliaga, 2019) on a medium office building built in 2001 also supports this conclusion. Based on this, we designed scenarios with VAV minimum airflow ranging from 50% to 10% to see how the reductions impact the DF performance.

As shown in **Figure 2**, as the VAV min damper position setting changes from 50% to 10%, the demand decrease intensity increases by 0.7 W/ft^2. So, this measure to reduce VAV minimum airflow leads to an increase in shed amount. In conjunction with the energy studies mentioned above, reducing VAV minimum airflow benefits both energy efficiency and demand flexibility. The shed amount dramatically increases as the VAV minimum airflow setting is reduced from 50% to 20%. There is a marginal increase in the median value of demand shed intensity when further decreasing the minimum airflow from 20% to 10%.

Figure 3 explains why we are seeing this trend. The example shown in the figure is a perimeter zone on the top floor on one of the 12 hottest days. Differences can be observed in the zone air temperature and VAV damper position trends during the GTA periods. At the beginning of the GTA period, i.e., when the DR event starts, the VAV damper with 10% minimum limit starts to close. It stops at 17%, allowing for the minimum airflow needed to reach the adjusted setpoint. In the 20% minimum scenario, it stops at the position of the minimum setting although 20% is close to 17%. The temperature coasting process is slightly slower than the 10% scenario. This explains why the 20% scenario has less shed than the 10% scenario but the difference is not significant. Major differences are observed in the 30% and 40% scenarios. The new set point with 4°F temperature adjustment can't be achieved, accounting for much less shed than the 10% and 20% cases. The 50% scenario on this example day does not respond to the GTA at all. In fact, 50% of airflow is much more than needed to maintain the setpoint even before the GTA period. It's overcooling during the day - its zone air temperature continuously stays at a lower level than the original setpoint. Thus, little shedding is observed in this scenario.

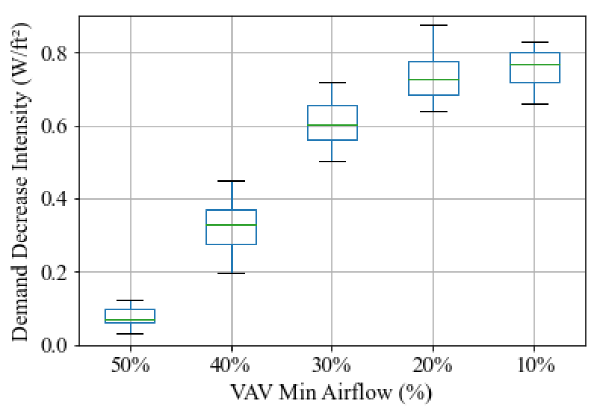

Figure 2. Demand decrease intensity increases as VAV min airflow is reduced

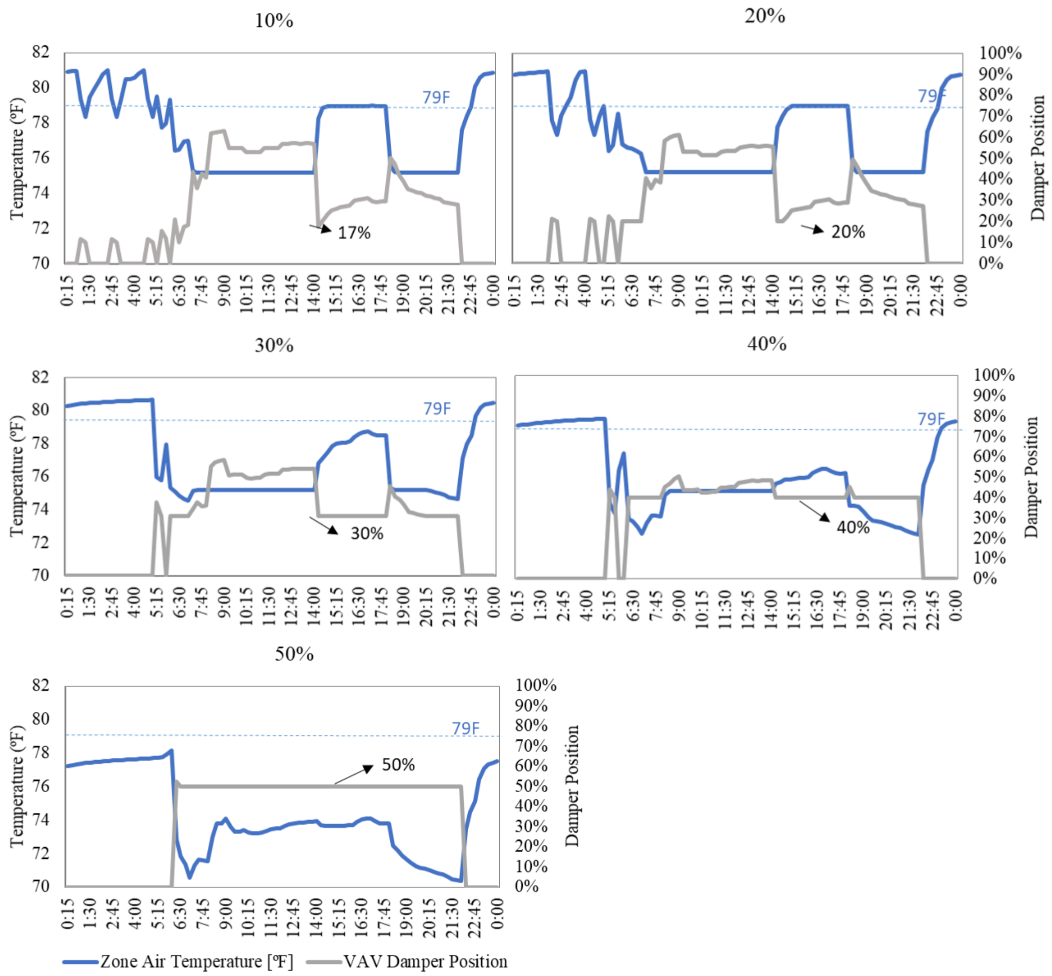

Figure 3. Zone air temperature and VAV damper position in one of the 12 hottest days for scenarios with different VAV minimum airflow settings

Enable Supply Air Temperature Reset. ASHRAE 90.1-2016 starts to require supply air temperature (SAT) reset based on outside air temperature for VAV systems in 3B climate. When SAT reset is enabled, the supply air temperature is increased when outdoor air is mild. It results in reduced compressor head and energy. In VAV systems, it also reduces reheat energy under minimum airflow modes, but increases fan energy when the zone cooling load required airflows are above minimum airflow settings. This is because more airflow is required to deliver the same amount of cooling energy when the supply and return air temperature delta is lower. The trade-off between the fan energy increase and compressor and reheat energy savings are specific to each building. In our study, we compared scenarios with vs without SAT reset strategy to evaluate its impact on load shed from GTA.

The left plot in **Figure 4** shows that the SAT reset has a fairly neutral impact on demand decrease intensity on the 12 hottest days. The change is not significant since the reset is rarely triggered on these hottest days. The right plot in this figure gives the full picture of the impact of SAT reset across a wider outside air temperature range by bins. It shows that SAT reset brings more shed in a lower outside air temperature range, especially when the SAT rest control sequence is most frequently triggered when the outside air temperature is between 50 ~ 70 ºF. Note that we picked the 12 hottest days for evaluation to represent when the traditional DR events most likely happen. However, DR is also used as grid emergency resources and events can happen on mild days when SAT reset can have a positive influence on load shed.

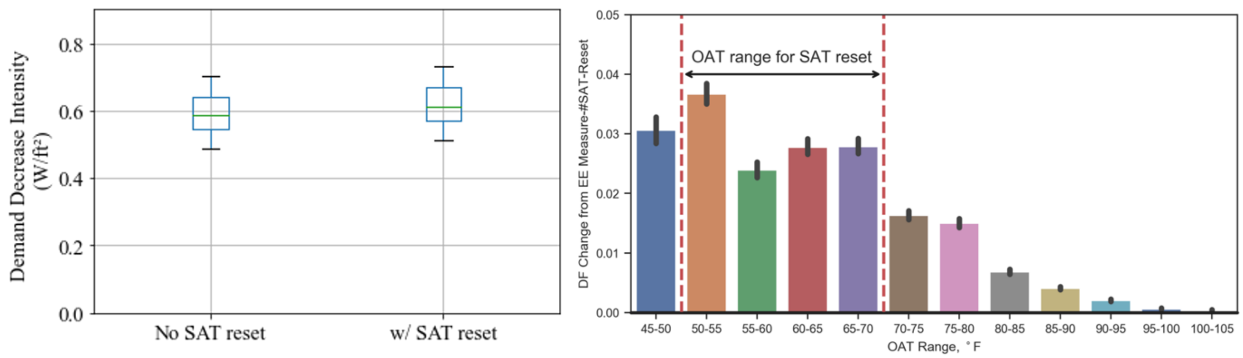

Figure 4. (Left) Demand decrease intensity for scenarios w/ vs. w/o SAT reset on 12 hottest days; (Right) Change in demand decrease intensity as a result of SAT reset binned to OAT.

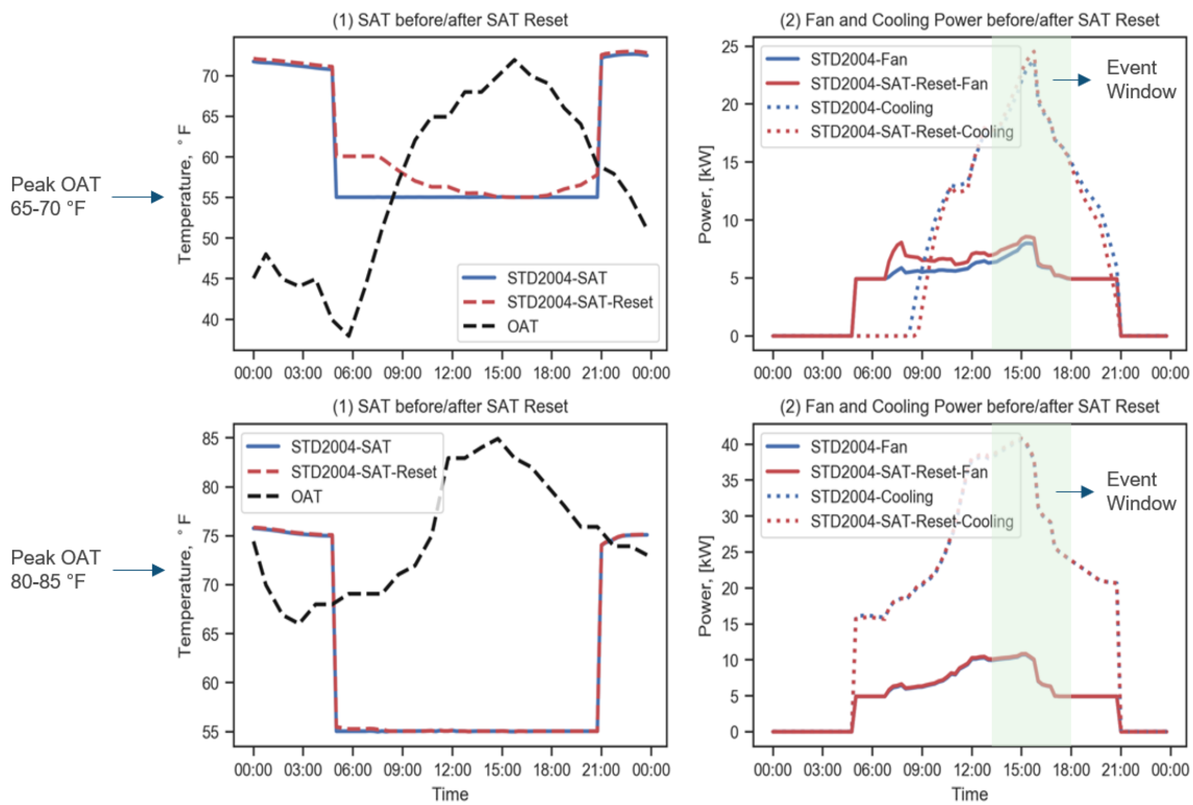

Figure 5 (1) SAT setpoint vs OAT. (2) Fan and cooling power before and after SAT reset. (Top: Peak OAT between 65-70 ºF; Bottom: Peak OAT between 80-85 ºF)

As previously stated, the SAT reset strategy leads to a decrease in compressor energy and an increase in fan power. **Figure 5** compares how these two energy components are balanced in the modeled prototype building. When the daily peak OAT is within 65~70ºF, the SAT setpoint increases from 55ºF to 56~57ºF as a function of OAT. As a result, there is a trade-off between the increased fan power and decreased RTU compressor power usage. During the shed hours, the baseline fan power increase outweighed the compressor power decrease. As a result, the shed is greater from the higher baseline load compared to no SAT reset. When the daily peak OAT is 80~85 ºF, SAT Reset is not enabled and the HVAC system operation does not change. In consequence, the impact of SAT Reset on the shed amount is minimal.

Raise Cooling Setpoint. A study using the same simulation software and prototype models as ours (Hoyt, 2015) has found that increasing the cooling setpoint from 72ºF to 77ºF results in an average of 29% cooling energy savings and 27% total HVAC energy savings without affecting occupant satisfaction level. Further raising to 86 ºF leads to 32%-73% energy savings. Based on this, considering common practice and occupant comfort, we use the cooling setpoint range to 70ºF - 76 ºF for our demand flexibility test.

The results shown in **Figure 6** indicate an increase of 0.66 W/ft^2 in demand decrease intensity as the original cooling setpoint (before GTA) is raised from 70ºF to 76ºF while the GTA adjustment is kept at 4ºF in all scenarios. **Figure 7** compares the zone air temperature coasting process to the adjusted new setpoint. It shows that when the initial cooling setpoint is higher the zone temperature coasting process slows down. This is because the zone cooling load is a function of the indoor-outdoor temperature difference. Therefore, increasing cooling setpoint not only saves cooling energy but also extends the period it takes for zone temperature to reach the new setpoint and allows the compressor to be off for longer – increasing the average load shed during the event.

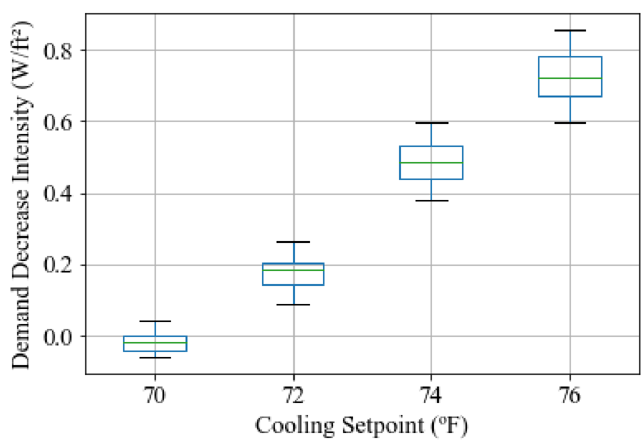

Figure 6. Demand decrease intensity of scenarios with cooling setpoint from 70ºF to 76ºF

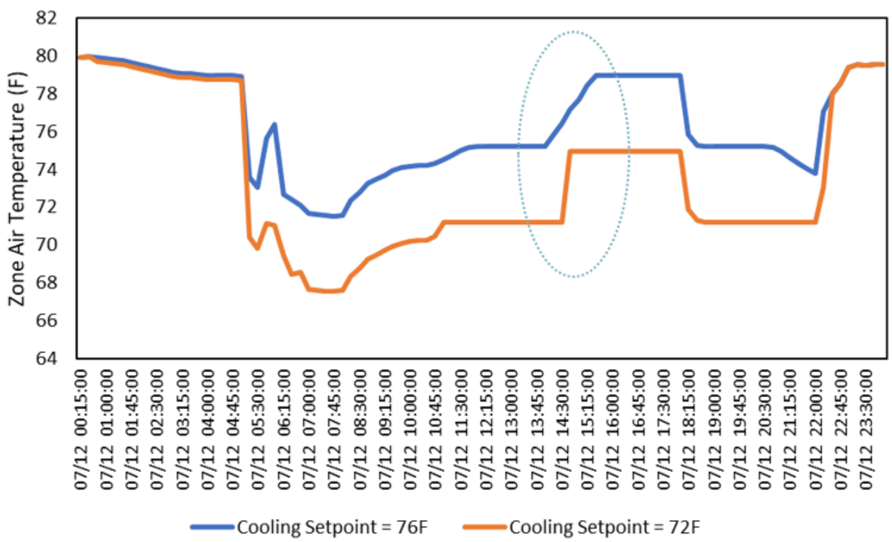

Figure 7. Zone air temperature coasting to adjusted setpoint for scenarios with an original cooling setpoint of 72 ºF vs. 76ºF

Packaged Measures. Three measures -- reducing VAV min airflow, enabling SAT rest, and raising cooling setpoint -- have been identified as individually increase the amount of shed. It would be useful to understand their combined effects.

We compared two scenarios. (1) The base efficiency scenario has no SAT rest, VAV min airflow at 30%, and cooling setpoint at 74 ºF. (2) The EE package scenario combines SAT rest, reducing the VAV min airflow to 10%, and raising the cooling setpoint to 76 ºF. As discussed earlier, SAT reset is typically enabled on mild days rather than the 12 hottest days. Thus, we also included a warm day with peak OAT ~75-80 ºF in the results in addition to the 12 hottest days, as shown in **Figure 8**.

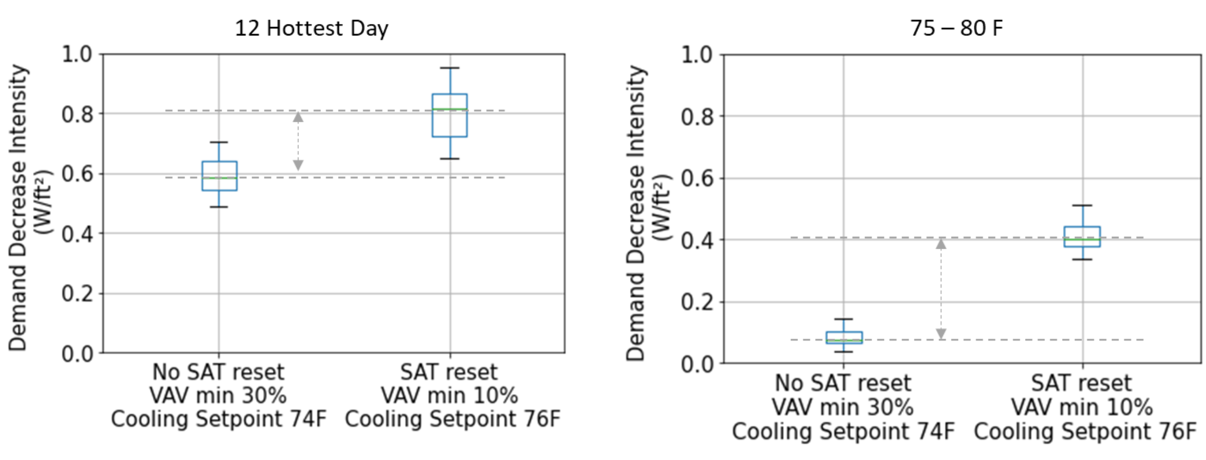

Figure 8. Demand decrease intensity of baseline scenario vs. packaged measures scenario. (Left) Comparison for the 12 hottest days; (Right) Comparison for days when the peak OAT is 75-80 ºF.

The left plot in **Figure 8** shows the results for the 12 hottest days. When applying these three EE measures together, the shed is increased by 0.21 W/ft^2. It's worth noting that the shed can be increased by 0.2 W/ft^2 by just raising the cooling setpoint from 74 ºF to 76 ºF alone (Figure 6). And reducing the VAV min airflow from 30% to 10% in isolation increases the shed by 0.18 W/ft^2 (Figure 2). The resulting shed from the packaged measures is only marginally greater than that of the individual EE measures. The right plot in **Figure 8** shows the results on a warm day (peak OAT in the 75-80 ºF temperature range) where the demand decrease intensity increases by 0.32 W/ft^2. This result indicates that the combined measure package provides a greater benefit on warm days compared to the hottest days.

Summary of Results

This study explored how EE influences DF on a measure-by-measure basis by using whole building energy simulation of a prototype medium office building (ASHRAE 2004 vintage) in the ASHRAE Warm-Dry climate. A total of 12 common EE features related to building systems including envelope, internal loads, and HVAC systems were included in this initial exploration and were combined with the GTA strategy to quantify their impact on demand flexibility. Nine of the EE measures have minimal or negative impact on the shed, measured by the *Demand Decrease Intensity* metric. The other three EE measures are identified to have a positive effect on the shed, i.e. increasing DF. Reducing the VAV minimum airflow setting from 50% to 10% increases *Demand Decrease Intensity* from 0.1 to 0.8 W/ft^2. Raising the cooling setpoint from 70 ºF to 76ºF also increases the *Demand Decrease Intensity* similarly from 0 to 0.8 W/ft^2. Applying supply air temperature reset provides more shed potential in a lower outside air temperature range (< 70 ºF) whereas it has a neutral impact on the hottest days. All of the above three EE features that compliment DF are in the HVAC control category. When applying the three measures in a package, i.e., reducing the VAV min airflow from 30% to 10%, raising the cooling setpoint from 74 ºF to 76ºF, and applying supply air temperature reset, could increase the *Demand Decrease Intensity* by 0.21 W/ft^2 on the hottest days and 0.32 W/ft^2 on warm days The combined result is less than the add up of the sheds from each individual measure.

Discussion of Practical Implications

This study identified three HVAC-control-related EE measures that compliment DF. It should be noted that this finding is limited to the specific building type, vintage, and climate zone covered in this study, which was intended as an example for early explorations. Future work shall expand the examinations on more building types, vintages, and climates. EE measures involved in this study is not exhaustive. Possible next steps will include more combinations of packaged measures. The DF impact results obtained from the simulation method are to be validated in practice. One known imperfection of the prototype models used in this study is that they don't have sufficient thermal inertia. There currently lacks specific guidance on how to adjust the simulation model for the results to be more accurate compared to measurements in real buildings.

With that said, these identified complimentary measures present an opportunity for offering low-cost integrated EE-DF measure packages in IDSM programs for greater energy cost savings for utility customers and increased program cost-effectiveness. Implementing IDSM programs in the commercial sector has its unique challenges in terms of justifying measure cost-effectiveness, M&V and expertise in the workforce as identified in previous studies (Starr et al.

2014, Riker et al. 2014). Identifying a few no-brainer measure packages with high cost-effectiveness that can work within the current imperfect regulatory framework will help create early wins and engage the customers. These measures fall in the retro-commissioning category and present a great opportunity for combined EE-DF audits in the retro-commissioning sales process. They generally do not require additional technical skills and therefore should be less challenging to implement by the current workforce, which again is a positive factor for creating early wins for the utilities and program implementers.

Acknowledgement

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References

Potter, J., Stuart, E. and Cappers, P., 2018. Barriers and opportunities to broader adoption of integrated demand side management at electric utilities: A scoping study. Lawrence Berkeley National Lab.(LBNL), Berkeley, CA (United States).

York, D., Relf, G. and Waters, C., 2019. Integrated energy efficiency and demand response programs. U1906. www.aceee.org/research-report/u1906

Starr, J., Preciado, J. and Morgan, W., 2014. Effective Integration of Demand Response and Energy Efficiency in Commercial Buildings. www.aceee.org/files/proceedings/2014/data/papers/4-960.pdf

Riker, C., Wang, K. and Yoo, F., 2016. Energy efficiency and automated demand response program integration: Time for a paradigm shift. www.aceee.org/files/proceedings/2014/data/papers/4-912.pdf

Present, E., Wilson, E., Speake, A., Adhikari, R., Gerke, B.F., Zhang, C., Satchwell, A., Murthy, S. and Piette, M.A., 2020. Modeling the Interaction Between Energy Efficiency and Demand Response on Regional Grid Scales (No. NREL/CP-5500-77423). National Renewable Energy Lab.(NREL), Golden, CO (United States).

Satchwell, A., Piette, M.A., Khandekar, A., Granderson, J., Frick, N.M., Hledik, R., Faruqui, A., Lam, L., Ross, S., Cohen, J. and Wang, K., 2021. A national roadmap for grid-interactive efficient buildings. Lawrence Berkeley National Lab.(LBNL), Berkeley, CA (United States).

Langevin, J., Harris, C.B., Satre-Meloy, A., Chandra-Putra, H., Speake, A., Present, E., Adhikari, R., Wilson, E.J. and Satchwell, A.J., 2021. US building energy efficiency and flexibility as an electric grid resource. Joule, 5(8), pp.2102-2128.

Gerke, B.F., Zhang, C., Murthy, S., Satchwell, A.J., Present, E., Horsey, H., Wilson, E., Parker, A., Speake, A., Adhikari, R. and Piette, M.A., 2022. Load-driven interactions between energy efficiency and demand response on regional grid scales. Advances in Applied Energy, 6, p.100092.

Munankarmi, P., Maguire, J., Balamurugan, S. P., Blonsky, M., Roberts, D., & Jin, X., 2021. Community-scale interaction of energy efficiency and demand flexibility in residential buildings. Applied Energy, 298, 117149.

Jewell, W., 2014, January. The effects of residential energy efficiency on electric demand response programs. In 2014 47th Hawaii International Conference on System Sciences (pp. 2363-2372). IEEE.

Present, E., Wilson, E., Speake, A., Adhikari, R., Gerke, B.F., Zhang, C., Satchwell, A., Murthy, S. and Piette, M.A., 2020. Modeling the Interaction Between Energy Efficiency and Demand Response on Regional Grid Scales (No. NREL/CP-5500-77423). National Renewable Energy Lab. (NREL), Golden, CO (United States).

Neukomm, M., Nubbe, V. and Fares, R., 2019. Grid-interactive efficient buildings (No. DOE/EE-1968). US Dept. of Energy (USDOE), Washington DC (United States); Navigant Consulting, Inc., Chicago, IL (United States).

Deru, M., Field, K., Studer, D., Benne, K., Griffith, B., Torcellini, P., Liu, B., Halverson, M., Winiarski, D., Rosenberg, M. and Yazdanian, M., 2011. US Department of Energy commercial reference building models of the national building stock.

Hoyt, T., Arens, E. and Zhang, H., 2015. Extending air temperature setpoints: Simulated energy savings and design considerations for new and retrofit buildings. Building and Environment, 88, pp.89-96.

Paliaga, G., Zhang, H., Hoyt, T. and Arens, E., 2019. Eliminating overcooling discomfort while saving energy.