Three Case Studies of the Application of Energy Systems Optimization Best Practices for Automatic Demand Response

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ABSTRACT

This paper summarizes three case study buildings located in Austin, Texas that were selected for inclusion in a review of the demand reduction program of the utility company Austin Energy. The buildings studied include a city government office building, a grocery store, and an industrial research office building containing high density data processing and server areas. This paper discusses the influence of the demand reduction measures on the indoor space conditions and HVAC system equipment, and cautionary notes regarding implementation for each measure. The objective of this study is to assess the feasibility of these facilities entering Austin Energy's demand reduction program.

INTRODUCTION

The overall goal of the demand response program is to reduce facilities peak energy demand to reduce the cost of electricity for both Austin Energy and their customer. Reducing the demand mitigates the need to construct additional generation, transmission, and distribution capacity as well as the risk of having to purchase expensive power on the open market during peak demand conditions.

Program participants must sign an agreement by which the customer acknowledges and agrees to curtail power usage during curtailment sessions that occur during the months of June, July, August, and September, on weekdays between 1pm to 8pm, excluding Independence Day and Labor Day.

Key program components that could affect the types of measures that will be effective include:

- Time periods when the curtailment sessions could occur (summer peak hours)
- Duration of the curtailment (up to 3 hours.)
- Prior notice given to the customer (1 hour.)

Incentive to participate in the program is a monetary incentive payment of $1.25 per kWh for avoided kWh during any curtailment session. Equation 1 shows the incentive calculation.

$$\text{Ins.} = \$1.25/\text{kWh} \times (P_{Base} - P_{CS}) \quad (1)$$

Where:

P_{Base} = average of the three highest kWh values in the 10 days prior to the curtailment session measured during the corresponding curtailment session hours

P_{CS} = the kWh measured during the curtailment session

Three different buildings were included in the demand reduction program: Austin Police Department Headquarters (APD), an HEB grocery store, and an IBM research facility.

DEMAND REDUCTION MEASURES

The goal of the DR programs for the utility company is to reduce the overall load of the system. The reduction of peak demand can happen through 3 methods: demand shifting, demand limiting, and demand shedding. **Demand shifting** happens when electrical consumption is moved to a different time in order to "level out" the demand curve and reduce the peak demand. While demand shifting does not have any energy reduction benefits, it does help utility companies better predict system loads and reduces the peak loads. **Demand limiting** happens when the energy consumption is limited to certain pre-determined load levels, and is restored when the loads have been reduced. **Demand shedding** is a temporary reduction of peak electrical loads. Demand shedding has the least impact on loss of building services because of its temporary nature, while demand limiting is more permanent (Motegi, et al., 2007).

Three major areas for DR opportunities can be identified: HVAC, lighting, and miscellaneous equipment (Motegi, et al., 2007). These three areas cover a majority of facilities, but more opportunities may be identified that are facility type specific or facility site specific and are not covered in this general overview of possible DR measures.

<u>HVAC</u>

Heating, ventilation, and air conditioning equipment includes distributed packaged equipment serving individual and multiple zones, as well as centralized heating and cooling equipment with distribution systems that include pumps and valves serving air handling systems to supply conditioned air. These systems are typically controlled by a Building Automation System (BAS), and can be grouped into zone equipment, distribution equipment, and central equipment.

The DR measures with HVAC system include indirect adjustments and direct adjustments. The detail is shown in the Table 1

Table 1: DR measures with HVAC system

Type	Content
Indirect Adjustments	Outside air ventilation - Increase CO_2 ppm setpoint
	Terminal boxes - Reduce maximum flow setpoint
	Increase space cooling setpoint - Absolute - Relative
	Increase space relative humidity setpoint.
Direct Adjustments	Outside air ventilation - Decrease OA cfm of air change rate setpoint - Limit OA at source
	Schedule vacant/unoccupied mode
	Terminal boxes - Disable reheat
	Air handling unit - Increase cooling coil temperature setpoint - Limit/close chilled water valve - Reduce static pressure setpoint (VAV system) - Reduce VFD speed (VAV system) - Inlet guide vane positioning (VAV system) - Turn units off
	Chilled water (CHW) system - Limit DP setpoint - Limit CHW pump VFD speed - Increase CHW setpoint - Demand limit chiller(s) - Turn off CHW system
	Heating system - Limit DP setpoint - Limit HW pump VFD speed - Turn system off

<u>Lighting</u>

Lighting includes task lighting and general zone lighting for interior and exterior applications. The DR measures with the lighting system are mainly defined by reducing lighting levels. Since most facilities cannot completely turn off lights for many areas, partially turning off lighting to reduce lighting level is the best measure.

Table 2: DR measures with lighting system

Measure	Content
Lighting level	- Reduce lighting level - Turn off portion of lights - Turn off garage lights

<u>Miscellaneous Equipment</u>

This measure involves turning off or reducing the use of all non-essential equipment. Table 3 shows a general list of common equipment. Within a facility more measures may be available including production equipment and hot process equipment like boilers.

Table 3: DR measure with Misc. equipment

Misc. Equipment Measures
Turn off refrigeration equipment
Turn off coffee makers and cold drink vending machines
Domestic Hot Water (DHW) systems - Reduce temperature setpoint - Turn off circulating pump - Turn off whenever possible
Turn off non-use computers and monitors
Unplugging charging equipment
Elevator cycling
Pool heating setpoint reduction
Turn off fountain pumps

ON-SITE DR MEASURES

Three different buildings selected by Austin Energy for the demand reduction program: Austin Police Department Headquarter, one HEB grocery store and IBM Austin research facility.

APD Headquarters

APD Headquarters, constructed in 1981, is a five-story building with a basement and has a gross area of 104,425 sq. ft. The building houses the police department headquarters, which consists mainly of office space. The single air handling unit (AHU) serving a majority of the building runs 24/7.

The BAS controls the central plant, AHUs, and terminal boxes. Equipment working schedules, fan speed, supply temperature of AHUs, and space temperature of terminal boxes can be controlled by the system.

Based on the site visit, 6 DR measures were developed for APD Headquarters. Table 4 shows the demand reduction measures for APD Headquarters.

Table 4: Proposed DR Measures of APD Headquarters

Demand Reduction Measure	System
DR1. Override fan speed of AHU-1	HVAC
DR2. Reset the space temperature setpoint	HVAC
DR3. Turn off decorative lighting, ice maker and vending machine	Misc.
DR4. Turn off the egress lighting	Lighting
DR5. Increase supply air temperature	HVAC
DR6. Shut down electric water heaters	Misc.

DR1. Override Fan Speed of AHU-1.

The fan speed of AHU-1 could be overridden to 30Hz during the demand reduction period. The demand reduction period can be 3 hours between 2:00 PM to 7:00 PM. Under this condition, the savings comes from fan power savings and cooling savings. At APD Headquarters, if the fan speed is overridden to 30Hz, the space temperature will increase from 72ºF to 80ºF with the relative humidity dropping from 55% to 42%. To allow the building facility personnel to select appropriate fan speed, the savings and space conditions under different fan speeds were provided.

DR2. Reset the Space Temperature Setpoint.

The space temperature setpoint can be adjusted from 72ºF to 78ºF during the demand reduction period. Actually, DR1 and DR2 can have the same result. The only difference between the two measures is DR1 is a direct adjustment measure; DR2 is an indirect adjustment measure. Customers can select one measure to implement from the two measures based on the BAS characteristics. As was the case with DR1, savings and space conditions under different space temperature setpoints were provided.

DR3. Turn Off Decorative Lighting, Ice Maker and Vending Machine.

Turn off the decorative lighting, vending machine, and ice maker during the demand reduction period. The electricity savings is calculated based on the power consumed by the equipment in kW and the number of hours that the equipment is turned off, shown in Eqn. 2.

$$\mathrm{ES}\ [\mathrm{kWh}] = \mathrm{P}\ [\mathrm{kW}] \times \mathrm{H} \qquad (2)$$

DR4. Turn Off the Egress Lights

In the building, egress lighting represents about 10% of the total lighting and is evenly distributed. Based on our on-site measure and investigation, we believe turning off the egress lighting will not make the lighting level too low to affect work.

$$\text{Saving} = 10\% \times \text{Total lighting} \times \text{Hours} \qquad (3)$$

DR5. Increase Supply Air Temperature.

This measure is dependent of the results from DR1. However, since the supply air temperature cannot be raised immediately, the effect on the demand is slower, and the savings will not be seen immediately. Additionally, this measure needs to be implemented very carefully since the increase in the supply temperature may cause condensation in the duct, which could reduce air quality.

DR6. Shut Down Electric Water Heaters.

In this measure, we consider to turn off the three electric water heaters. Assuming 5 people/1000sqft **Error! Reference source not found.** and 0.1 gallon/hr./person (ASHRAE, 2011), the hot water flow can be calculated. Based on the hot water flow, the amount of energy required to heat the water can be calculated.

Potential Savings: APD.

Savings calculations assume 15, 3-hour curtailment events each year. Base on the incentive payment rate of $1.25 per kWh and an avoidable cost of $0.06093 per kWh (Austin Energy, 2013; Austin Energy, 2012), the yearly total estimated savings were calculated and shown in Table 5.

Table 5: DR Measures and Savings of APD Headquarter

DR Measure	Savings (kWh) (15 - 3hr events)	Total Savings ($)
DR1	1,011	$1,325.35
DR2	*832*	*$1,090.69*
DR3	360	$471.93
DR4	244	$319.87
DR5	408	$534.86
DR6	171	$224.17
Total*	**2,234**	**$2,928.62**
***the total number is the sum of DR1, 3, 4, 5 and 6 since DR2 and DR1 are related and both of them reach the same task.**		

IBM Austin Research Facility

The IBM Austin Research Center includes 7 office buildings: 901, 902, 903, 904, 905, 906 and 908, which share similar properties and demand consumption patterns. Therefore, the main demand reduction measure of the report (setting back the AHUs fan speed) will be presented solely for building 901 since the results can be extrapolated to the remaining buildings. The peak demand during the summer for Building 901 is approximately 1,750 kW.

The measures presented in Table 6 have been selected based on their applicability to the Demand Reduction (DR) program set by Austin Energy.

Table 6: Proposed DR Measures of IBM

Demand Reduction Measure	System
DR1. Override fan speed	HVAC
DR2. Shut down electric water heaters	Misc.
DR3. Shutdown of garage lights	Lighting

DR 1 and DR 2 are similar with the DR measures we mentioned above in the APD Headquarters section. Following the same steps, we estimated the savings and space temperature and relative humidity conditions.

DR3. Shut down garage lights.

This measure suggests turning off the garage lights during curtailment period. Additionally, safety guidelines would have to be considered to implement DR3 before shutting down the garage lights.

Potential savings: IBM.

Savings calculations assume 15 3-hour curtailment events each year. . Base on the incentive payment rate of $1.25 per kWh and an avoidable cost of $0.05816 per kWh (Austin Energy, 2013; Austin Energy, 2012), the yearly total estimated savings were calculated and shown in Table 7.

Table 7: DR Measures and Savings of IBM

DR Measure	Savings (kWh) (15 – 3hr events)	Total Savings ($)
DR1	5,748	$ 7,519.30
DR2	5,913	$ 7,735.15
DR3	6,300	$ 8,241.41
Total	**17,955**	**$ 23,488.01**

HEB #269

This is a grocery store with 11 roof top units serving the whole building area. 7 of the 11 units were replaced in 2012 since the old roof top units were not working properly during the previous summer. There are no skylights on the building roof and all the illumination is provided by artificial lighting. The on-site control system serves to monitor the space condition and equipment working status by the facility personnel. All setpoints and unit operations are controlled remotely in another facility and the store personnel has no control over the system to either change setpoints or shut off devices.

A grocery store is functionally different when compared to an office building. In the grocery store, the comfort feeling of customers and product keeping requirements are extremely important and need to be considered when DR measures are implemented.

Based on our on-site investigation and information provided by building facilities, ESL engineers developed supplementary demand reduction measures for HEB #269. Unlike the previous two sites mentioned in the report, the HEB grocery stores had already joined the DR program of Austin Energy, and had already implemented one DR measure. The recommended measures for HEB #269 are presented in Table 8.

Table 8: DR Measures of HEB #269

Demand Reduction Measure	System
Previously Implemented Measure	
DR0. Shut down RTUs 1 through 7	HVAC
Additional Measures	
DR1. Turn off 40% lighting	Lighting
DR2. Reset the space temperature setpoint	HVAC
DR3. Turn off of standby the off-duty computers, registers and credit card machines	Misc.
DR4. Turn off the ice maker serving the seafood department	Misc.

DR1 Turn off 40% lighting.

In the current BAS system, the lighting switch control is dividing the lighting into 40% and 60% capacity. Under current control system, 40% lights could be turned off during the demand reduction period and 60% lights could be turned off during unoccupied period. This translates into about 600 lighting bulbs being turned off during demand reduction period.

DR2. Reset the space temperature setpoint for RTUs 8 through 11.

The space temperature setpoint could be adjusted during the demand reduction period from 72ºF to 78ºF.

DR3. Turn off or set to "standby mode" the off-duty computers, registers and credit card machines.

Not all of the Checkout counters are on duty during the demand reduction period. Without considering the advertisement function of the monitors, we believe the off-duty computers, registers and credit card machines can be switched off during the demand reduction period.

Based on the ASHRAE Handbook, assuming a 2.3 GHz processor, 3 GB RAM desktop and 380mm (15 inch) screen monitor, the average power is 49W and 19W, respectively (ASHRAE, 2009). The savings are directly related to how many off-duty computers, registers and credit card machines can be switched off. It might be changed based on the sales conditions.

DR4. Turn off the ice maker serving the seafood department.

The ice maker that serves the seafood department could be shut down during the demand reduction period since the ice maker usually has its heavier duty hours during the morning. In the afternoon (demand reduction period) the ice maker could be shut down for at least two hours and if necessary it could be turned back on. The practical running schedule of the ice maker should be based on the sale conditions. For savings calculations we assume the power of the ice maker with a size of 1000lbs/day is about 4kW (roughly 1kW per 250lb of ice) (ASHRAE, 2005).

Potential savings: HEB.

Savings calculations assume 15 3-hour curtailment events each year. . Base on the incentive payment rate of $1.25 per kWh and an avoidable cost of $0.04864 per kWh (Austin Energy, 2013; Austin Energy, 2012), the yearly total estimated savings were calculated and shown in Table 9.

Table 9: DR Measures and Savings of HEB #269

DR Measure	Savings (kWh) (15 - 3hr events)	Total Savings ($)
Implemented Measure		
DR0	1,995	$ 2,590.79
Additional Measures		
DR1	875	$ 1,135.66
DR2	315	$ 409.07
DR3	31*	$ 39.74
DR4	180**	$ 233.76
Total	**3,395**	**$ 4,409.01**

* Assuming 10 computers and monitors
** Assuming a 1,000 lb ice maker

SAVINGS ANALYSIS

The calculated results show that the DR measures are estimated to reduce 11.0% of building demand at APD headquarters, 22.8% at IBM building and 12.6% at HEB #269.

To simplify the calculation, we assume the building load keeps constant when the space temperature and relative humidity are changed. The building load includes internal load and envelope load. Changing the space condition from 72ºF to 78ºF does not change the sensitive internal load and has a little influence on the latent load. The envelop load usually takes 10% to 20% of the whole building load depending on the envelop materials. And if the space temperature goes from 72ºF to 78ºF when the outside air temperature is about 100ºF, we calculated the total building load is reduced about 2% to 5%.

Based on the calculated result, cutting down the fan speed or increasing space temperature setpoint can change the space temperature significantly, in our case it is from 72ºF to 78ºF, but the space relative humidity does not have apparent changes. The space relative humidity had a 10% drop for APD headquarters and IBM building and kept constant at HEB #269.

AUTOMATED DR POTENTIAL

For the sites surveyed, almost all of the HVAC Measures are associated with systems that are currently fitted with automatic controls and therefore can be automated or at least semi-automated while almost none of the Non-HVAC measures have automatic controls installed; or if they are, the control system does not have the control granularity that would be required to achieve fully automatic DR.

The results suggest that an Auto DR Program expansion should focus on HVAC measures, and level Non-HVAC measures should be implemented later as more Non-HVAC loads are controlled by the BAS. Future work should include verifying the above through further field study of actual buildings similar to the site surveys reported here.

FUTURE WORK

The calculation of potential savings for the site surveys has resulted in a simplified method for estimating the demand reduction potential. The method requires some basic information about the systems being analyzed and follows a prescribed order.

First, the measures are split into two groups:

- Non-HVAC measures – these are associated with equipment or processes that are not associated with the HVAC system.
- HVAC measures – these are associated with equipment or processes that are an integral part of the HVAC system.

This is done primarily because the Non-HVAC measure identified can typically be characterized by a single value for demand that is not influenced by any other factor other than being active or inactive. In fact, even the HVAC measures share this behavior to some extent if only the hours when a DR session is likely to occur are considered. But, there is enough variability in prevailing weather conditions across the applicable time period to warrant this distinction; and it also will allow for expanding the calculation methodology to apply to other days as well.

Perhaps more important to the accuracy of the calculations than the above dichotomy, the order of the calculations must be considered so that interactive effects between measures is accounted for and the final result does not overstate the DR potential.

For this, it was necessary to further break down the DR measures into DR measure types that correspond with the interactive influences. For the purpose of DR potential estimation, the biggest influence comes from the reduction in DR potential for certain measures that result from the implementation of other measures. Therefore, the measures are further split into the following:

- Environmental Load Reduction Measures - DR measures that result in a reduction in the environment load (the load that exists at peak) regardless of whether or not HVAC can meet the load.
- Non-Environmental Load Reduction Measures - DR measures that do not result in a reduction in the environmental load.

Non-Environmental measures may affect the HVAC system's ability to meet the load by limiting the effect of one or more components within the system, but they do not impact the load itself. Figure 1 presents the order in which the types of DR measures should be implemented.

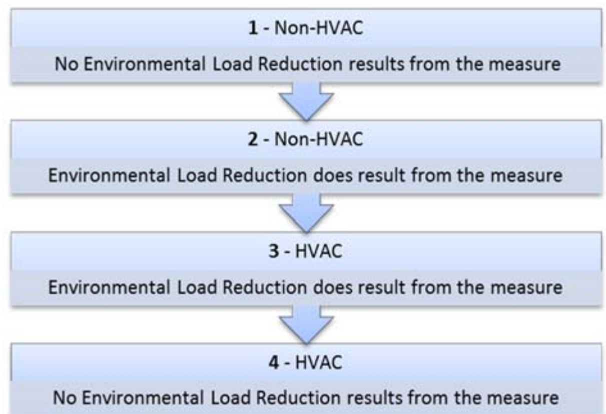

Figure 1: DR method flow chart

Preliminary comparisons of calculated results to actual results are promising, but more work is needed to verify that the methodology reasonably estimates the potential DR in a wide range of cases.

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