Local Government's Guide to Maximizing Demand Response Income in PJM Interconnection Region and Symbiotic Energy Efficiency Benefits

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ABSTRACT

Local governments can find it difficult to navigate through the complex conditions of demand response (DR). Some stay away from the DR programs altogether or otherwise limit their participation because the incentives don't match the complication and perceived risk. This paper is a cost-analysis template for local government owners in the region of PJM Interconnection to evaluate the three primary demand response strategies for existing buildings with limited capital investment: global temperature adjustment (GTA), lumen level lighting control (LLLC) and generator operation. Two supporting technologies that could be implemented during new construction or renovation improve the likelihood using GTA are also explored: window films, and energy recovery ventilators (ERVs). All strategies are projected to be cost-effective. The paper provides real-life examples of City of Alexandria's experiences with implementing DR and simple algebraic formulas for estimating potential income of other portfolios.

LLLC and ERVs show improved financial outcomes (a reduction in simple payback time by 20%, and 73% respectively) when including the demand response savings in addition to the standard energy efficiency returns, demonstrating how demand response could positively benefit the uptake of those energy conservation measures more broadly. GTA and generators have the best simple payback at under one year for large buildings (250,000 square feet) and slightly slower payback at smaller building sizes (2 years at 70,000 square feet), but like window films do not save energy on an annualized basis even though they can help save demand.

Introduction

Demand Response Programs

The PJM Interconnection territory serves over 67 million people from Pennsylvania, New Jersey, Maryland, Rhode Island, Delaware, Ohio, West Virginia, Virginia, and parts of Kentucky, North Carolina, Indiana, Illinois, and Michigan, (PJM, 2026). This region is incurring increasingly heavy electric demand due to a variety of factors, such as, but not limited to: construction of new data centers, increase in electric vehicles, hotter summer temperatures, normal population growth, electrification, etc. These changes are generally occurring without the development of new electrical transmission, and a slow increase in generating capacity, thereby increasing the number and duration of high demand days - often associated with the summer months. Thus, demand response programs were created to incentivize the reduction in peak demand on critical days. Demand response programs help the utilities avoid the initial costs of adding more "peaker-plants" (power plants only turned on during extreme load conditions – often less than 100 hours per year), provide demand response participants a source of income, and better balance electric supply and demand.

This paper is targeted for government facilities in the PJM territory for five reasons:

- the sum of available demand reduction of this sector estimated at >100 MW which is greater than some small power plants,
- government buildings have similar occupancy hours,
- government buildings are more flexible in setting operational conditions
- all the facilities are in climate zones 3A, 4A, and 5A, excluding extreme climates
- City of Alexandria's experience as a local government implementing demand response can provide value to other facilities in this zone

PJM provides three demand-response programs:

- The Synchronous Reserves (SR) program gives a 10-minute pre-warning, followed by a demand response that usually lasts under 20 minutes. Incentive of $60,000/MW (2026)
- Emergency Load Response Program (ELRP) allows for a 30-minute to 120-minute pre-warning (permissions dependent), and up to an 8-hour demand response by the utility. Incentive of $120,000/MW (2026)
- Elective responses set by user for either price or carbon.

Strategies

Darwazeh et al's 2022 paper "Review of peak load management strategies in commercial buildings" is a literature review of demand response strategies and implementation from over 120 sources around the world and is a repeated reference for this paper. This paper answers the questions what are the primary, successful strategies for implementing demand response on commercial building. Due to its breadth of research, it provided a good foundation for expansion and further discovery into the current cost-effectiveness of different solutions.

While some buildings can design demand response-focused technology into new buildings or modify existing ones to include hydronic storage tanks, dimmable glass, battery storage, this paper is mostly focusing on technologies which are more likely to be present in existing, government facilities or most cost-effectively implemented at equipment renewal. The three primary building strategies being considered are:

- Global Temperature Adjustment (GTA) (Motegi, 2007) of the HVAC system zones
- Stationary Emergency Generators
- Lumen Level Lighting Control (LLLC)

Strategies: Stationary Generators

Stationary generators application to demand response up until recently has been greatly limited by emissions interpretations. Within the last year the EPA has clarified restrictions on diesel gen-sets, so they are now able to run 50 hours of demand response (Enel, 2025) regardless of emissions tier. This will greatly expand to the use of back-up diesel generators to be run during demand events. Activated emergency generators used in these instances will run the emergency building loads, which are approximately 1/10th to 1/6th of a building's energy demand based on City of Alexandria's experience.

Strategies: Global Temperature Adjustment

All occupied buildings have HVAC systems, which makes the market penetration of implementation more possible. While there are many sub-strategies to the HVAC demand response, the one that is most-implemented is GTA as it affects multiple HVAC components simultaneously (plant, distribution, terminal devices) by changing one set-point in the Building Management System (BMS).

The general premise of GTA is that at the start of the demand response period, the zone temperature set-point is raised (or in the case of winter operation, lowered) to allow the building temperature to float to the new set-point temperature. The sudden change of temperature set-point, eliminates the load for a period, stopping the compressors, slowing or stopping distribution systems such as chilled water pumps, condenser water pumps, fan speeds, etc. The thermal mass of the building effectively becomes the temporary source of space conditioning.

With GTA demand response strategy building occupants are in the thermal storage system, rather than the thermal storage being a separate HVAC component. Due to the building occupants' location with respect to the thermal storage, one of the most critical attributes of the GTA strategy is maintaining thermal comfort of the spaces. ASHRAE Standard 55 (ASHRAE, 2023) sets boundaries for comfort. Variables of acceptable comfort include relative humidity, dry-bulb temperature, air-speed, clothing levels, and metabolic rates, assuming no direct solar gain on the occupant. UC Berkeley has a useful tool "CBE Thermal Comfort Tool" which provides the Predictive Mean Vote (PMV) based on those variables. It shows that given a static air-speed condition, clothing, and metabolic rates, (60% RH, 1.1 Metabolic rate, summer casual business attire, 19 fpm air-speed) that the maximum range of acceptable temperatures is ~8 degrees Fahrenheit dry-bulb temperature (72-80 degrees) assuming adjustable clothing amounts during the day. For example: business jacket in the morning and short sleeves in the afternoon.

Therefore, the maximum demand response duration using GTA is defined by the ability to maintain ≤ 8 degrees dry-bulb temperature change, and the maximum rate of temperature change per time (ASHRAE Standard 55). Given an existing building and keeping the primary buildings components (envelope, HVAC, etc), to maximize the duration in the demand response, the building zones should all be at the ends of comfort temperature range at the start of the demand response period.

ASHRAE Standard 55 limitation for temperature increase is a maximum increase of 4 degrees Fahrenheit change per hour. Use of shorter demand response programs, like SR would allow for deeper market penetration while also complying with the existing tenant agreements on temperature setpoints. If the demand response event in SR or other program is limited to 30 minutes or less, a two-degree change may not even be experienced or noticed by tenants.

For the buildings which may be open to longer demand response events, Darwazeh et al indicates another common strategy that is used in conjunction with GTA to maximize the duration of the demand response: pre-cooling. Pre-cooling shifts the peak of the building load curve from the typical afternoon to the morning by cooling the building a few degrees lower in the morning and holding that temperature until the demand response time. It changes the load shape without increasing the peak power. While often-times additional energy is spent holding a lower interior zone temperature longer than normal, depending on the GTA strategy, demand response program and building, the energy savings during the demand period can (but infrequently) fully negate the additional, morning cooling energy use. Such energy-neutral events would occur if there were a load-shedding action (eliminating some cooling load) along with the load-shift of pre-cooling.

The following two days shown in the graph are for the same building with similar outside air temperatures, but have different responses being either the baseline or a day with pre-cooling followed by a demand response event. Both days use almost identical amounts of energy while providing comfortable temperatures to occupants during the occupied periods.

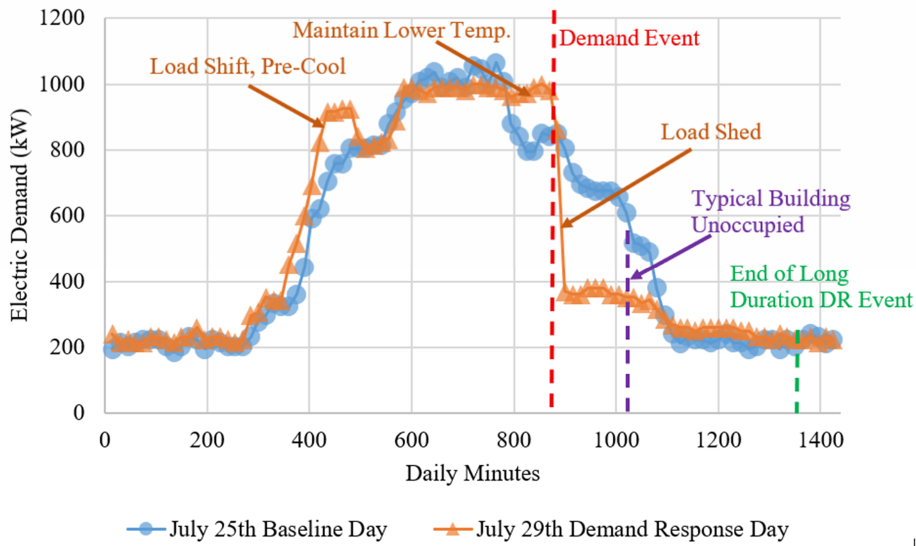

Figure 2: Comparison of demand the same City of Alexandria building: standard response versus pre-cooling plus demand event

Strategies: Lumen Level Lighting Control

LLLC is defined by LED fixtures with continuously dimmable lighting controls which are connected to the building management system. LLLCs are similar in nature to automatic daylighting control, which can slowly dim and brighten to maintain a constant lumen lighting at the desk surface in proximity to varying daylight (clouds, sun, orientation, etc). The only difference between this discrete applications of advanced lighting controls for LEDs, is the further ability to connect them to a single point controller in each zone which is then addressed to a Building Management System. During periods of demand response, the BMS, can slowly turn down the brightness to minimum acceptable levels over the span of 15-20 minutes, over-riding current user-occupied setpoints. The slow change in lighting levels over this period is virtually unnoticeable to occupants by design.

Lumen level lighting control on the other hand, generally requires the lighting system be specified at the time of installation with BMS control to gain the benefit, and one of the reasons it is often excluded from implementation due to the higher capital cost. However, LLLC is widely available and is increasing in prevalence in new construction and renovation applications in part due to the high degree of dimming control. Local government owners should consider LLLC at renovation or new construction.

Strategies: Energy Recovery Ventilators

All occupied buildings need fresh air ventilation. However, commercial buildings' cooling loads are mostly defined by the ventilation load (and the window characteristics – see following section). That is the reason these upgrades were specifically selected for inclusion in the analysis. Energy Recovery Ventilators collect the heat and humidity from one stream of air (for example summer outside air conditions), and run the air through a heat exchanger which absorbs the heat and moisture and transfers it to another air-stream leaving the building. These leaving air-streams are usually from bathrooms or in densely populated occupancies like gyms and classrooms, neutral exhaust air required to maintain the building pressurizations. Like building envelope insulation, as outside air temperatures move towards the extremes (very cold or very warm), ERVs provide improved energy savings. Therefore, this technology is well suited for demand savings, as they provide the most energy savings when the grid demand is going to be at their highest. None-the-less, the ERVs generate demand response income because they provide the right conditions for more comfortable occupancy (minimum required ventilation at low load) during the implementation of global temperature adjustment while in an ELRP event.

Strategies: Window Films

Window films are almost exclusively added to existing glass to restrict solar gain in the summer. Being that the peak summer demand occurs between the hours of noon and 10PM, and given the presence in the Northern Hemisphere, the South and Western exposures are most important to have good solar control for purposes of demand response. For the purposes of this paper and limiting cost, the windows films will only be included on Southern and Western exposures. It should be noted that on new construction or newly renovated buildings, that new windows with low SHGC (generally below ~0.27) would likely be acceptable solar control.

Like ERVs, window films are not assumed to reduce demand directly, and are considered as a comfort improvement during the implementation of the GTA during an ELRP event. Window films presence improves the likelihood of keeping a building in an HVAC pause for the entire, proposed eight hours ELRP. Because both the ERV and window films rely on the implementation of GTA with the ELRP, their income in Results Table 4 is not additive. They only are additive by improved comfort during an ELRP event or the increased duration of time the facility can to stay in demand response.

Unfortunately, unlike ERVs, research by LBNL demonstrates that on average window films in climate zones four and higher cause buildings to lose more energy on an annualized basis, because they also restrict heat gain which is useful in the winter. As one would expect, the colder the climate zone the more annual energy losses window films cause.

Table 1: Whole Building Energy Savings When Adding Window Films (Kim, 2024)

Climate Zone	Avg % Savings
2	3.5%
3	1.0%

4	-1.0%
5	-1.2%

Previous Research

"Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction" paper by Fernandez, Z (2017), on the synergies between energy efficiency and demand response establishes that maintaining a building, finding faults in operation, and integrating control upgrades both decreases demand and improves energy efficiency on a cost-effective basis. This paper takes those findings as a default condition and establishes that including a Building Management System and keeping a building functioning as designed is a baseline for implementing any future strategy (GTA, LLLC, and diesel generators). While diesel generators are not often connected to the BMS, diesel generators can be easily integrated into the BMS control to force a backup generator ON and OFF on command and at a cost-effective price point.

The research paper "Load-driven interactions between energy efficiency and demand response on regional grid scale" (Gerke, 2022) focuses their attention at grid-scale operators and demand response program managers for the purpose of incentivizing behaviors and developing programs. In contrast to the target top-down audience, which is a rational consumer market for new research, this paper's audience is focused on providing advice and information to the end-consumer as they are ultimately making the decisions to participate. Gerke et al. specifically indicates two areas left unevaluated: "we do not analyze the impacts of EE or DR … on the cost-effectiveness of individual EE or DR measures, and we identify this as an important opportunity for future research" and "We do not consider changes in customer willingness to participate in EE or DR programs." While this paper does not claim to definitively answer all aspects of these two segments of missing but valuable research, by highlighting the current anecdotal responses to these questions while also providing a framework for other local governments to evaluate their own portfolios, will allow for self-generation of additional data for future collection while encouraging and advising local governments on potential adoption of demand response technologies which also meet their other energy efficiency and climate goals.

Other papers also delivered to ACEEE's Summer Study on Building Energy Efficiency have also included similar themes of evaluating demand response and energy efficiency programs. However, a majority of the papers merging energy efficiency and demand response are focusing on the programmatic aspects of a utility, state, or commission selecting effective methods to implement demand response. None of them to the author's knowledge provide guidance from the perspective of an average, existing, commercial building owner on specific methods to participate, associated income, and cost-effectiveness.

A logical next step in research, and not covered by this paper, would be the dissemination of information provided in this paper to local governments followed by either surveys of whether information provided increased the likelihood of participation in demand response or inclusion of additional technologies studied. As part of that survey, collation of the relative cost and cost-effectiveness of demand response or energy efficiency technologies would resolve a major source of uncertainty – discussed at greater length in the methodology section.

Methodology

Assumptions

The primary benefit of DR to government and other portfolio owners is income potential, with secondary benefits of alleviating the grid from brown-out and occasional carbon savings. As described in the introduction, utilities indicate the $/MW or $/KW of electric demand reduced by program type, but only go the next step of estimating income based on a short test of the demand response after the owner selects the method of compliance and implementing. While a physical test is a reasonably accurate estimate of load reduction because it measures the actual load during the test, it requires that the government building owner commit to some amount of financial outlay in controls programming or other investments and leaves open the possibility of investing in a technology which provides limited financial gain. Additionally, utilities do not advise on what technologies or methods to include in renovations and whether such technologies would be cost-effective. These are the gaps this paper attempts to fill by using information available to a government building owner in the PJM region.

One major theme of this paper is on maximizing income. Therefore, for the ELRP response, it assumes that with appropriate pre-cooling and air-mixing that the HVAC pause can last the duration of an 8 hour stretch while the interior temperature slowly changes under the 8 degree limit as described in the introduction. Other strategies of gradually changing zone set-points over time, called steps, can offer slower changes in zone temperature and potentially improve comfort, but at some fractional percentage of the income potential depending on building configuration. GTA steps are not covered in this paper as it does not maximize income. However, these variations of GTA should be considered for less-efficient buildings that would not be able to participate in ELRP otherwise. Future research could evaluate performance of different HVAC system types, compressors, capacities, and number of stages to determine the magnitude of change relative to the maximum.

Income from elective responses by price and carbon are primarily dependent on the levels of cost or carbon the owner chooses as a threshold for demand response. In a thought experiment, if an owner chose $0.00/ kWh as the price to do demand response then the building would be doing demand response all the time. In the process the owner may end up making the building largely unusable if using GTA or would exceed the regulatory limit of 50 annual run-time hours while using emergency generators. Conversely, if that value were $1000/kWh then the demand response would never turn on. The same pattern applies to using carbon as the trigger for demand response initiation. Therefore, the usefulness of evaluating income for elective responses is solely dependent on user preference and the current, highly variable power market. The owner would frequently have adjust the thresholds to balance building use and occupancy needs against price or carbon savings. As a result, the elective program is ignored for the purposes of determining cost-effectiveness and income while remaining consideration is given to the more static and defined programs of the SR and ELRP.

From City of Alexandria's experience, finding existing buildings that are capable of 8 hours of an HVAC pause, associated with the ELRP and GTA strategy are usually commercial buildings built or substantially renovated after the year 2000, and have the following attributes:

- Building management system,

- Energy Recovery Ventilator(s) (for providing fresh air at reduced heating/cooling load while the building is occupied but the HVAC is paused), and
- have high-performance windows

Two standard buildings representative of two buildings in the City of Alexandria will be used for evaluation of each measure to give an understanding of the facilities, make comparisons, and provide inputs for example calculations:

Table 2: Example Building Parameters for Use in Financial Calculations and Results

Building Type	**Office Building**	**Recreation Center & Office**
Square Feet	250,000	75,000
Number of Stories	10	2
Year Built	2000	1960 with Renovations 1990s
Window to Wall Ratio	40%	25%
Cooling Method	Water Source Heat Pump with Cooling Tower	Primarily Air-cooled chillers and direct expansion
Effective Cooling COP	4	3
Heating Method	Electric Resistance VAV box	Hydronic gas w/ VAV box
Peak Billed Demand	1,100 kW	326 kW
Lowest Billed Demand	700 kW	300 kW

Capital costs and incremental capital costs are two large sources of uncertainty when determining accurate simple payback and net present value calculations. While reasonable estimations of costs can be made using typical labor and material rates, the costs that local governments experience can be many times over fair market value due to upcharges and common contractor opinions that a large entity, such as a local government, with a large budget deserves a higher price, irrespective of the scope or scale of the services provides. Additional variations such as use of proprietary controls vendors as opposed to open-source controls may also skew initial costs. The costs used in the examples are actual values from recent implementation of such measures (controls, ERVs) or where no anecdotal example existed from published sources. Uncertainties in costs could easily range between 0.5 to 2 times the costs used in the examples, so caution should be taken if trying to extrapolate to other facilities without first completing the calculations provided here-in.

Metrics

Simple payback is an elementary evaluation of cost-effectiveness. As the name implies, it is a simple calculation and one that owners apply. Net Present Value (NPV) is also a metric that owners use but is further complicated by variable costs of lending. Governments across different states have slightly different lending rates which are going to result in different cost-effectiveness numbers. Additionally, lending rates change over time for the same user based on the base Federal Reserve interest rate. Due to the extra computation length NPV results for each scenario will only be represented in a table with different interest rates. Microsoft Excel equations will be the primary determination of calculating NPV. The same annual savings and incremental costs will be used for both simple payback and NPV though applied in the different formulas. Simple payback is included with the formula derivation and example results using specific, example buildings (one with gas heating, one with electric heating).

It is standard practice in energy analyses to include energy and standard demand savings (as applicable based on utility schedule) when considering upgrading building components. However, per ASHRAE 211 Standard for Commercial Building Energy Audits (ASHRAE, 2018), it includes the option for adding demand response into the annual cost savings calculation. This attribute will be included as part of the calculations. The basic formula and beginning of the derivation for simple payback is as follows:

Equation 1:

$$\text{Simple Payback} = \frac{\text{Incremental Costs}}{\text{Net Annual Cost Savings}} = \frac{\text{Incremental Costs}}{\text{DR Income} + \text{EnergyCostSavings} - \text{GenreatorUse}}$$

Where:

Incremental Costs = are capital costs above baseline required to successfully implement demand response actions such as but not limited to controls or new equipment

Net Annual Cost Savings = Sum of annual expenses and income as a result of implementing demand response

DR Income = Income from Demand Response programs (SR and ELRP)

EnergyCostSavings = Cost Savings from energy reductions because of implementing demand response (Not always present)

GeneratorUse = increased energy cost from demand implementation, such as generator fuel

The following equations are expanded simple payback formulas for different conditions, which can be used by portfolio managers at their desks to estimate the current simple payback. Assumptions listed are numerical values from the two example buildings and entered into the associated formulas. All example outputs are listed in the Results section.

Equation 2:

$$GTA - SR = \frac{Incremental\ Cost}{\left[kW_{peak} - (kW_{lowest} * 0.75)\right] \times SRIncentive \times \%Time_1}$$

Where:

- $GTA - SR$ = estimated simple payback from synchronous reserves using Global Temperature Adjustment HVAC strategy (< 30 minutes duration)
- *Incremental Cost* = are capital costs above baseline required to successfully implement demand response actions usually associated with controls additions
- kW_{peak} = highest billed kW (most likely summer kW, but potentially winter)
- kW_{lowest} = lowest billed kW (likely in a shoulder season - spring/ fall)
- $SRIncentive$ = cash incentive for synchronous reserve demand response ($/kW)
- $\%Time_1$ = fractional percentage of 8760 annual hours are available to reduce demand

Assumptions for example calculation:

- Incremental cost = $10,000 for writing new programming to control setback (City of Alexandria actual expenditure).
- $\%Time_1$ = 42% Office Building; 30% Recreation Center
- With GTA strategy, there are no energy savings (kWh) and no extra energy consumption (This may or may not be true in other buildings)
- $SRIncentive$ = $60,000/MW = $60/kW
- 0.75 multiplier times the kW_{lowest} variable is there to estimate the actual kW associated with the HVAC pause during the demand response event. The lowest billed kW is actually the highest kW during the billed month, even if it is the lowest billed in the year. Therefore, this multiplier approximates the actual low kW. If other 30-minute data from the utility company is available, that can substitute for the entire (kW_{lowest}-*0.75) part of the equation.

Equation 3:

$$GTA - ELRP = \frac{Incremental\ Cost}{\left[kW_{peak} - (kW_{lowest} * 0.75)\right] \times ELRPIncentive \times \%Time_2}$$

Where:

- *GTA - ELRP* = estimated simple payback received from ELRP using Global Temperature Adjustment HVAC strategy (up to 9 hours DR duration)
- $\%Time_2$ = Fractional percentage of 4745 annual hours are available to reduce demand (6AM – 9PM Winter, 10AM – 10PM Summer, (PJM, 2025))
- $ELRPIncentive$ = cash incentive for ELRP demand response ($)
- See Equation 2 variable definitions as needed

Assumptions for example calculation:

- Incremental cost = $10,000 for writing new programming to control setback
- $\%Time_2$ = 90% Office Building; 29% Recreation Center
- With GTA strategy, there are no energy savings (kWh) due to pre-cooling and holding temperature at a lower (or higher) set-point until the start of demand response
- $ELRPIncentive$ = $120,000/MW = $120/kW

Equation 4:

$$Emergency\ Generator\ SPB = \frac{[CostofInitialDRConnection]}{[ConnectedkW * (ELRPIncentive + SRIncentive)] - \left[\frac{kWGeneratorOutput}{GeneratorEff} * \frac{3{,}412\ Btu}{kWh} * \frac{HrRuntime}{Year} * \frac{gallons}{137{,}000 Btu} * \frac{\$}{gal_{Diesel}}\right]}$$

Where:

- $Emergency\ Generator\ SPB$= estimated Simple Payback of running emergency generator during a demand response event (Years)
- *ConnectedkW* = the electrical load powered by the emergency generator (kW)
- $SRIncentive$ = cash incentive for synchronous reserve demand response ($/kW)
- $ELRPIncentive$ = cash incentive for ELRP demand response ($/kW)
- *kWGeneratorOutput* = maximum generator electricity output (kW)
- *GeneratorEff* = Fuel to wire efficiency (%)

- $HrRuntime$ = annual generator run-time (hours)

Assumptions for example calculation:
- CostofInitialDRConnection = \$10,000 for integration of existing ATS into BMS
- Rated Generator Output = 265 kW
- ConnectedkW= 100 kW
- $\frac{\$}{gal_{Diesel}}$ = \$3.70/gallon
- GeneratorEff = 35%
- Annual Generator Runtime for Demand Response = 50 hours
- Generators can run for the entire duration of demand response so there is no need for time multipliers. Alternatively, $\%Time_1 = \%Time_2$ = 100% (not shown).

The following Equations 5 through 7 are targeted towards upgrade selections that can be made at renovations of an existing building or building of new construction, rather than low-cost implementation of controls with existing components.

Equation 5:

$$LLLC\ SPB = \frac{[Incremental\ Cost\ of\ LLLC]}{BldgLightkW * 0.62 * \left[0.24 * [(ELRPIncentive * \%Time_2 + SRIncentive * \%Time_1)] + \left[0.25 * (1 + \frac{1}{COP_{Cooling}}) * \frac{\$}{kWh} * \left[\frac{OpHrs}{Year}\right]\right]\right]}$$

Where:
- $LLLC\ SPB$ = Lumen Level Lighting Control (LLLC) Simple Payback estimate
- $BldgLightkW$ = Sum of Lighting Power connected to LLLC (kW)
- $SRIncentive$ = cash incentive for synchronous reserve demand response (\$/kW)
- $ELRPIncentive$ = cash incentive for ELRP demand response (\$/kW)
- $\%Time_1$ = fractional percentage of 8760 annual hours are available to reduce demand
- $\%Time_2$ = Fractional percentage of 4745 annual hours are available to reduce demand (6AM – 9PM Winter, 10AM – 10PM Summer)
- $COP_{Cooling}$= Coefficient of Performance of Cooling System
- $\$/kWh$ = blended (includes supply and demand) electric rate in dollars per kWh
- $OpHrs/Year$ = Estimated total occupancy hours of connected lighting (hours)
- 24% Lumen Level Lighting Control demand savings (Darwezeh, 2022)
- 25% energy savings from LLLC (NEEA, 2025)
- *38%* energy savings from standard lighting control (occ sensors, timers, etc.). Williams, 2012. This results in (1-0.38) = 0.62 multiplier on total lighting kW.

Assumptions for example calculations:
- Enrollment in both the ELRP and SR demand response programs
- Energy Savings are achieved through a reduction in cooling demand as well as direct lighting savings reductions.
- Cost of light increase by \$40/fixture (NEEA, 2024)

- o 0.64 Watts/ square foot (2021 VA Energy Code)
- o $\frac{\%Time}{ELRP\ Period}$ = % of the ELRP timeframe (6AM – 9PM winter, 10AM – 10PM Summer) that the demand response action is available for implementation. 0.60 for office and 0.67 for recreation center.

Equation 6:

$$Simple\ Payback\ Window\ Films = \frac{Capital\ Cost}{\left[\left(kW_{peak} - (kW_{shoulder-peak} * 0.75)\right) * ELRPIncentive\right] + \left[BlgElecUse * NRELWinFilmSavings * \frac{\$}{kWh}\right]}$$

Where:

- o *BldgElecUse* = Annual kWh of whole building (kWh)
- o *$/kWh* = average annual electric rate ($/kWh)
- o *NRELWinFilmSavings* = Average whole building % energy savings from Table 1.

Assumptions for example window film Simple Payback:

- o Implementation of window films supports for use of GTA via the ELRP program
- o Assumes that the SR program with use of GTA is already in place
- o Cost of Implementing window films is $15/square foot (Concord, 2026).

Equation 7:

$$ERV\_SPB_{@RTUReplacement} = \frac{\left[\frac{\$2000}{TonsCooling} * TonsCooling\right]}{\left[\frac{TonsCooling \times 12{,}000}{DX\_COP \times 3412} \times ELRPIncentive\right] + [ElecSavings + GasSavings]}$$

Where:

- o $ERV\_SPB_{@RTUReplacement}$ = Estimate of Simple Payback of adding an ERV during an RTU replacement
- o *TonsCooling* = nominal tonnage of RTU compressor(s), (tons)
- o The $2000/Ton Cooling is inclusive of the ERV and new ductwork
- o *ElecSavings* = Estimation of electric energy savings associated with including an ERV. Calculated from spreadsheet of 8760 annual hours and outside air rate ($)
- o *GasSavings* = Estimation of gas savings associated with including an ERV. Calculated from spreadsheet of 8760 annual hours and outside air rate ($)

Assumptions for example ERV Simple Payback:

- o Implementation of ERV allows for use of GTA via the ELRP program
- o Assumes that the SR program with use of GRA is already in place
- o TonsCooling = 15 tons for the example calculation

Results

The data in the following Table 3 & 4 are showing cost-effectiveness by Simple Payback and Net Present Values when both example buildings, detailed in Table 1, have values and other assumptions under each derived formula entered into the equations. Results for all options except window films are based on real values experienced at City of Alexandria. Window film costs and savings are projected.

Table 3: Results of Example Existing Buildings' Demand Response Strategies

DR Strategy & Program	Example Building	Annual Income	Simple Payback	Net Present Value & Associated Interest Rate			
				(3%)	(4%)	(5%)	(6%)
GTA - SR	Office	$14,490	<1 year	$110,000	$103,000	$97,000	$91,000
	Rec Center	$2,250	4 years	$9,000	$8,000	$7,000	$6,000
GTA - ELRP	Office	$62,100	< 1 year	$505,000	$475,000	$447,000	$422,000
	Rec Center	$6,450	2 years	$44,000	$41,000	$38,000	$35,000
Generator, SR & ELRP	Office	$14,500	< 1 year	$110,000	$103,000	$97,000	$91,000

Table 4: Results of Example Renovation & New Construction Demand Response Strategies

DR Strategy & Upgrade	Example Building	DR Income	Energy Income	Simple Payback	Net Present Value & Assoc. Interest Rate			
					(3%)	(4%)	(5%)	(6%)
LLLC SR & ELRP	Office	$1,100	$13,500	9 years	$44,000	$31,000	$20,000	$10,000
	Rec Center	$800	$5,800	6 years	$38,000	$32,000	$27,000	$23,000
Window Film GTA + ELRP	Office	$56,700	-$5,400	8 years	$367,000	$296,000	$234,000	$180,000
	Rec Center	$15,020	-$1,500	6 years	$230,000	$217,000	$206,000	$195,000
ERV, GTA + ELRP	15ton RTU	$2,200	$800	10 years	$14,000	$10,000	$7,000	$4,000

Discussion

The example Results demonstrate the potential for highly advantageous financial gain for the inclusion of demand response using: existing building components, buildings with a building management systems (BMS), maximum income as a goal, and technical maximum compliance with ASHRAE 55 comfort. The primary reason for this financial gain is the comparative, low cost of implementing new and basic programming, and outside of some potential new wire for the ATS integration little to no new hardware is required. Additionally, the implementation of Global Temperature Adjustment with the HVAC system (as the largest single source of power consumption on a commercial building) provides opportunity for steep kW reductions – yielding a comparatively large financial return. The degree to which

Note that even though the Synchronous Reserves appears to provide only half the potential income from Emergency Load Response Program, ($60/kW versus $120/kW), SR actually earns 3-4 times less than ELRP because the time the buildings need to be available for a Synchronous Reserves event overnight by program rules, though are almost guaranteed to not comply for city facilities. ELRP more closely mirrors occupied hours and therefore is more likely to achieve higher participation than SR.

The largest potential income is associated with ELRP and the use of strategies/technologies that allow for Global Temperature Adjustment. Most ELRP responses are in the summer months, when electricity demand across the PJM Interconnection region is highest. However, winter demand response requests are almost guaranteed, which greatly reduces the available income for those buildings which are heated with gas versus heated with electricity. Because the buildings are not available during the winter, their participation rate plumets. From the results, though the example Recreation Center heated with methane gas is 3.3 times smaller in square feet than the Office Building, the available ELRP income for the Recreation Center is ~10 times smaller than the electrically heated Office. The Recreation Center $\%Time_2$ variable from the equation and assumptions is also 3 times smaller than the office building (29% versus 90%) which explains the net difference in performance: 3.3 * 3 = 10.

Interestingly, the results from Table 4 show the ability for certain energy efficiency technologies to have improved financial outcome when including demand response income. For example, the Lumen Level Lighting Control (LLLC) and the Energy Recovery Ventilators (ERVs) are technologies that both benefit by demand response and energy efficiency incomes. LLLC shows a 20% quicker simple payback because of the inclusion of demand response.

Meanwhile, the energy conservation measure which is the real winner of demand response income is the ERV. Although the example shows comparatively low financial performance due in part to the small size of the 15-ton RTU example, retrofitting an RTU with an ERV and additional ductwork costs $30,000 but the energy savings is only $800/year (gas heating). Therefore, with energy-efficiency alone the simple payback is 37 years, longer than the lifetime of an RTU or stand-alone ERV. The example ERV using energy savings alone also has a negative net present value (not shown in Results). However, if implementation of ERV also allows the implementation of the GTA at the zone in question, then the simple payback decreases by a factor of 3 and net present value is positive. Furthermore, once the infrastructure with ducts and distribution is in place, the subsequent RTU/ ERV replacement will be even more cost-effective.

Not every RTU can gain energy and demand income benefit of an ERV due in part to the need for a source of heat recovery. In the example, the 15-ton RTU is within 30 feet of locker-room and bathroom exhaust flows which are equal to the outside air flow intake rate. Other locations like gymnasiums, auditoriums, conference rooms, classrooms etc. may have RTUs with existing exhaust relief (other than economizer operation) that run on a constant basis to account for high ventilation demand while limiting over-pressurization. Those RTUs could use the existing exhaust air as the heat recovery provided. RTUs that have an existing, reasonably close source of exhaust air are some unknown fractions of the overall number of RTUs in existence. Therefore, this solution is not a panacea to every RTU. Further research could be dedicated to understanding the potential market penetration and impact of ERVs with use of demand response, GTA as an additional source of income.

Conclusion

All five of the measures evaluated for government facilities demand response programs within the PJM Interconnection region demonstrated both beneficial Simple Payback and Net Present Value. The greatest financial opportunity is the global temperature adjustment (GTA) strategy while implementing the emergency load response program (ELRP) and synchronous reserves (SR) at the same building(s). The next most financially advantageous technologies include existing back-up generators and lumen level lighting control (LLLC). However, the most interesting finding was that implementing demand response at replacement or new construction of buildings with LLLC and energy recovery ventilators (ERVs) may expand the implementation of those energy efficiency technologies due to their improved financial outcomes. Therefore, building owners should evaluate the potential income from demand savings when taking on a new project or renovation, which may also help them with their long-term energy efficiency or climate goals.

Not every building may be possible to implement all demand response actions or fully maximize the income as indicated in this paper, due to variations in existing building conditions, occupancy, and subjective determinations on acceptable indoor environmental quality changes. Modifications to the strategies such as providing "steps" on the temperature setbacks during implementation of GTA with the ELRP, or use of the shorter duration SR program may provide implementation at a greater number of facilities. However, buildings that have a greater percentage of the following attributes are more likely to gain from either the ELRP, SR, or both:

- Building Management System
- Efficient Envelope (characteristics better than code year 2000)
- Larger facilities with greater kW demand
- energy recovery ventilator on outside air flows
- Low SHGC window films on Southern and Western exposures
- Generator
- Advanced lighting associated with lumen level lighting control

By using the equations and information in this paper, it is possible to estimate PJM Interconnection territory government buildings' maximum demand response income potential with information available at a facility managers' desk.

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AI-assisted tools used: claude.ai.
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