Dynamic Controls for Energy Efficiency and Demand Response: Framework Concepts and a New Construction Case Study in New York

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ABSTRACT

Many of today's advanced building control systems are designed to improve granularity of control for energy efficiency. Examples include direct digital controls for building heating, ventilation, and cooling systems (HVAC), and dimmable ballasts for continuous dimming for daylighting applications. This paper discusses recent research on the use of new and existing controls in commercial buildings for integrated energy efficiency and demand response (DR). The paper discusses the use of DR controls strategies in commercial buildings and provides specific details on DR control strategy design concepts for a new building in New York. We present preliminary results from EnergyPlus simulations of the DR strategies at the New York Times Headquarters building currently under construction. The DR strategies at the Times building involve unique state of the art systems with dimmable ballasts, movable shades on the glass facade, and underfloor air HVAC. The simulation efforts at this building are novel, with an innovative building owner considering DR and future DR program participation strategies during the design phase. This paper also discusses commissioning plans for the DR strategies. The trends in integration of various systems through the EMCS, master versus supervisory controls and dynamic operational modes concepts are presented and future research directions are outlined.

Introduction

Reliable supply of affordable electricity is the key goal for the electric power systems. During the past few years, blackouts in the Northeast and California have caused billions of dollars of losses to businesses and individuals ([ELCON]; Lawton et al. 2003). Recent improvements in developing and demonstrating demand response (DR) in electricity markets address challenges related with reliability and economics. Demand response can be defined as short-term modifications in customer end-use electric loads in response to dynamic price and reliability information.

This paper explores the premise that advanced building controls in commercial buildings provide an excellent resource for demand response. This paper also describes new concepts regarding advanced controls for DR, linking DR capability to new and existing energy management control systems (EMCS) and new lighting controls. In the U.S., seven percent of all commercial buildings corresponding to 31% of the commercial floor space use energy management and control systems (Kiliccote & Piette 2005; [CBECS]).

Commercial buildings are a major contributor to summer peak demand, with large increases in cooling requirements on hot summer days. Recent estimates on the role of this sector in driving summer peak demands suggest that commercial buildings account for 330 coincident GW which is 45% of the total for the entire U.S. summer peak demand (Kiliccote, et al, 2006). To address this large load, studies on automated DR in 28 commercial buildings in California indicate that a short-term reduction of five to ten percent of the peak summer electric demand is feasible in many buildings with existing EMCS (Piette et al. 2005). The potential demand response in commercial buildings with EMCS by utilizing the existing EMCS nationwide is estimated between 5 to 10 GW.

This paper begins with an introduction of a demand-side management (DSM) framework for energy efficiency, peak load management and demand response. The paper then describes recent work at The New York Times building systems within the DSM framework. Next, we present estimated peak demand savings derived from DR simulations for the Times building. This is followed by a discussion of the financial implications of the DR savings under various DR programs offered by the local utility and New York Independent System Operator in the area. We end with a discussion of next steps in specifying the DR sequences and how they fit with the envisioned future of building controls.

Demand-Side Management Framework for Commercial Buildings

Electricity demand varies constantly. At times of low demand, only the lowest marginal cost plants operate, while at peak times, almost all of available power plants run to meet demand. Electricity providers and their customers are concerned with peak demand because of the financial and environmental challenges of providing growing electric system capacity. DOE summarized the value of DR in a report to the U.S Congress as "resource-efficiency of electricity production due to closer alignment between customers' electricity prices and the value they place on electricity" (DOE 2006).

The demand-side management (DSM) framework presented in Table 1 provides three major areas for changing electric loads in buildings: energy efficiency (for steady state load minimization); peak load management (for daily operations); and demand response (DR) (for event driven dynamic peak load reduction). In this paper, we present the DSM framework from a buildings perspective concentrating on EMCS and lighting control system based options. In this paper, load and demand are used interchangeably.

Table 1. Energy Efficiency, Daily Load Management and DR

	Demand-Side Management		
	Efficiency and Conservation (Daily)	**Peak Load Management (Daily)**	**Demand Response (Dynamic Event Driven)**
Motivation	- Utility bill savings - Environmental Protection	- TOU Savings - Peak Demand Charges - Grid Peak	- Price - Reliability - Emergency
Design	- Efficient Shell, Equipment & Systems	-Low Power Design	- Dynamic Control Capability
Operations	- Integrated System Operations	- Demand Limiting - Demand Shifting	- Demand Shedding - Demand Shifting - Demand Limiting
Initiation	- Local	- Local	- Remote

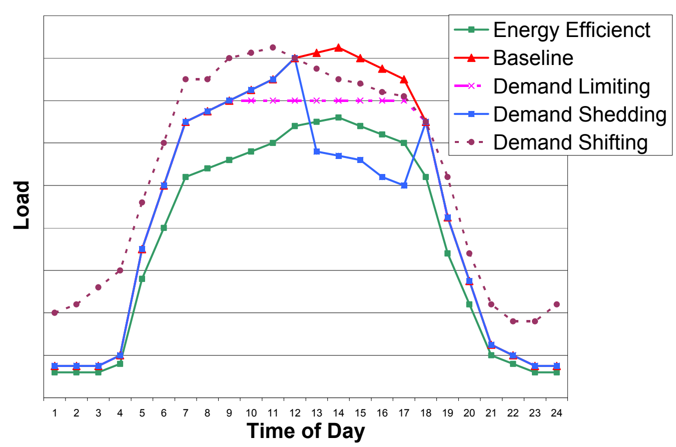
Energy efficiency. Energy efficiency and conservation can lower energy use to provide the same level of service. Driven by the desire for utility bill savings and environmental protection, energy efficiency measures permanently reduce peak load by reducing overall consumption. In buildings this is typically done by installing energy efficient equipment and operating buildings efficiently.

Daily peak load management. The advance of metering technology made it possible to differentiate electricity usage patterns of buildings. Peak load management is motivated by high charges for peak demand and time-of-use rates. Typical peak load management methods include demand limiting and demand shifting. *Demand limiting* refers to shedding loads when pre-determined peak demand limits are about to be exceeded. Loads are restored when the demand is sufficiently reduced. This is typically done to flatten the load shape when the pre-determined peak is the monthly peak demand. *Demand shifting* is shifting the loads from peak times to off-peak periods. Figure 1 displays the typical demand profile of a commercial building employing these methods.

Demand response. Demand response refers to the modification of customer electricity usage at times of peak usage in order to help address system reliability, reflect market conditions and pricing, and support infrastructure optimization or deferral. Demand response programs may include dynamic pricing and tariffs, price-responsive demand bidding, contractually obligated and voluntary curtailment, and direct load control or equipment cycling. DR methods such as demand limiting and shifting can be utilized when the economics and reliability issues are predicted and communicated to each site in advance. *Demand shedding* is dynamic temporary reduction, or curtailment of peak load when dispatched and refers to strategies that can be possibly implemented within a shorter period of response time.

Initiation row of the table indicates if the activity is a result of a local or a remote requirement set forth by the facility or an outside entity such as a utility.

Figure 1. Demand Profile of Various Demand Response Methods



While developing any DR strategy, it is important to identify and differentiate closed-loop and open-loop strategies. ***Open loop control***, such as a demand limit, may constrain building systems and produce zones and areas of a building that are out of standard comfort zones. ***Closed loop control*** strategies with resets maintain control within zones and systems. Another important concept is that as we develop demand responsive buildings, we no longer have simple modes of operation such as warm up, full occupant, and night set back. Rather, we have ***dynamic set point control*** relative to the electric load shape objectives for the building and the time varying cost of electricity. Another important concept on advanced controls for demand response is as we improve the ***granularity of control***, we increase the DR capability. The concept of granularity refers to how much floor area is covered by each controlled parameter (e.g., temperature). This is true for both heating ventilation and air conditioning (HVAC) and lighting. Improvements in controllability, such as zonal HVAC or zonal lighting, allow us to potentially work with some parts of the building for a DR event, but perhaps not all of it. Or, advanced controls and increased levels of granularity allow us to define explicit steps in building services (lighting or temperature) that can potentially be exercised during DR events.

The New York Times (NYT) Building and its Demand-Side Management

Lawrence Berkeley National Laboratory (LBNL) researchers have been working with the design of the new NYT headquarters building in Manhattan to integrate control of lighting and shading devices, to commission the lighting systems, and to develop DR strategies and DR controls specifications for the building. In this section, brief description of the building systems including energy efficiency and low power components are highlighted and the DR process is outlined.

The headquarter building was designed to promote "transparency" to the public with floor-to-ceiling clear glass windows shaded by a unique exterior shading system combined with interior shades. The key objective of the design and construction effort is enhancing the way employees work, with sustainable building design and energy efficiency as a natural consequence. The NYT shares the fifty two-floor building with another company and only occupies floors 2 through 28. The building's geometry with its all-glass exterior is a major constraint. Therefore, systems design attention concentrated on energy efficient building components and systems as well as low power design.

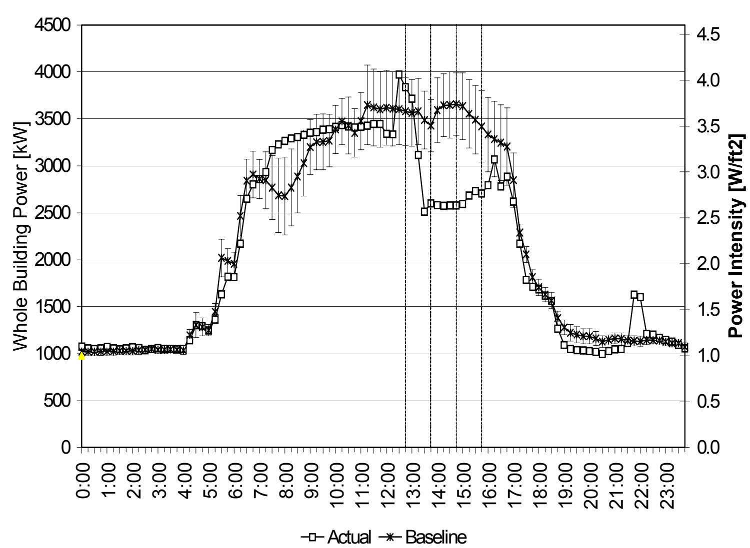
From the owner's perspective, since occupant satisfaction is the key objective, the overall intent for interior shading controls is to keep the shades up as much of the time as is possible without causing thermal or visual discomfort (Lee et al. 2004). Thermal comfort is assured by luminance sensors located outside for solar tracking and the geometry of the external sunscreens. As the location of the sun changes throughout the day, shades are operated to cut off direct solar gain. Visual comfort is assured by managing the luminance on the window wall. The specified lighting controls system is an enhanced Digital Addressable Lighting Interface (DALI) based system with dimmable fixtures throughout the interior space. This allows the system to dim down the electric lighting in response to daylight levels registered by an illuminance sensor located on the ceiling, to assign local target values, and to enable dimming of all lighting from a central location via central command. DALI provides additional flexibility by providing dynamic grouping of lighting fixtures to accommodate varying workspace requirements and layouts.

Floors two through five are called podium floors and are about 55,000 ft^2. They house The Newsroom. These floors are serviced by eight air-handling units (AHU) and a cogeneration unit located on the roof of the podium. Each tower floor, with usable area of 19,000 ft^2, has its own AHU. The AHU's supply high-pressure air (0.5 inch) to the main ducts. These ducts are called “air super highways”. Dampers are connected to the air super highways and supply 0.05 inch pressure to the low pressure under floor plenum. There are adjustable and relocatable swirl diffusers at each workstation. This is a pressure-controlled system with temperature sensors located at the perimeter columns for space temperature and one temperature sensor at the core of the building measuring return air temperature. Air is returned through the diffusers in the lighting system and into a large ceiling plenum. Each tower floor has 6 HVAC zones with each zone having one static pressure sensor and one temperature sensor.

The building systems and the owner’s preferences provided a framework and identified constraints for DR strategy development. The owner requested that any common equipment, such as the chiller plant, and common spaces would be exempt from DR work. In addition, the developed DR strategies would be implemented floor-by-floor depending on occupancy and other priorities. Initial DR control strategies were proposed as follows:

HVAC system. Global set point adjustment strategy is recommended. Global set point adjustment is the ideal DR strategy for HVAC systems. It is a term used for increasing the cooling set point and decreasing the heating set point therefore relaxing the lower and upper limits of the set point dead band. The acceptability of set point adjustment strategy depends on how much, how fast, how often it is executed and other occupant related issues such as their layers of clothing, information provided to them, etc. Figure 2 displays the demand shedding effect of global set point adjustment in a large office building that participated in the Automated DR test sites in California (Piette et. al, 2005). At this site, the demand response event was three hours. The fictitious price rose to \$0.30/kWh for the first hour, peaked at \$0.75/kWh for the second hour and decreased to \$0.30 for the last hour of the event. The baseline was developed considering the last ten days prior to the DR event, adjusted for weather. The error bars represent the standard error in the baseline model. For the NYT building, the initial recommendation was increasing the set point 3 °F for moderate demand reductions and an additional 3 °F for further demand reductions. The 3 °F change was proposed as a starting point for the simulations. Iterations of the temperature gradient were expected depending on the simulated temperatures within the zones.

Figure 2. The Demand Shedding Effect of Global Set Point Adjustment



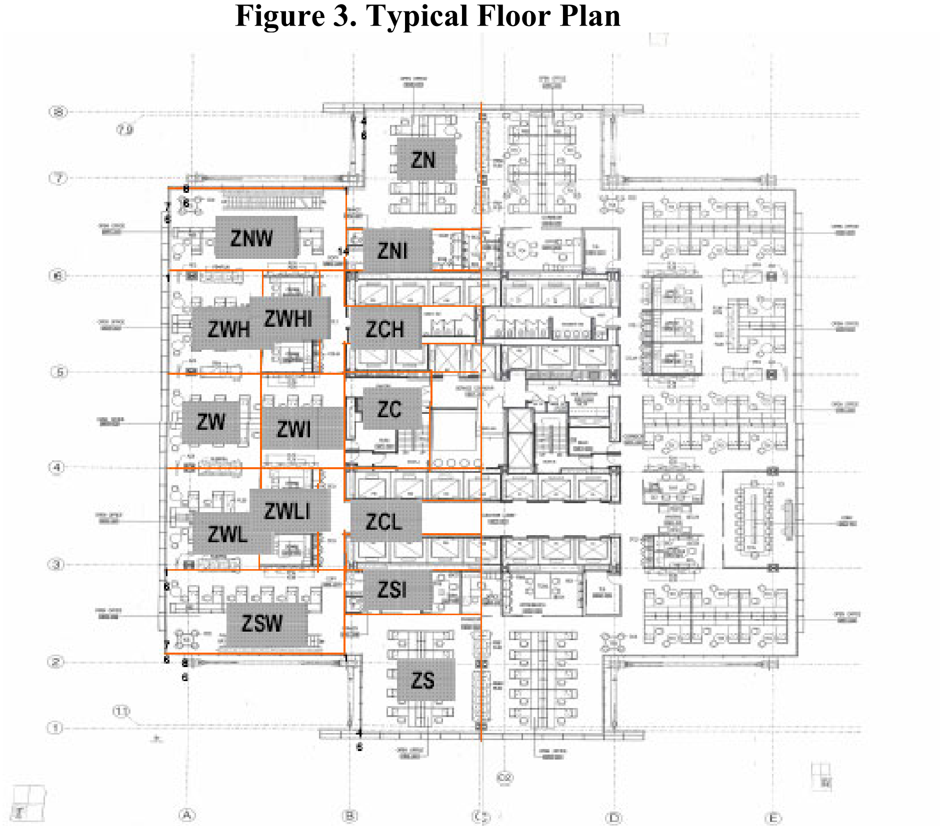
Lighting system. The DR strategy should provide two stages of lighting control. Stage 1 is defined as lowering all perimeter daylight configuration zones by 70% and all zones close to the central core by 50%. During Stage 2, perimeter lights are turned off. Any time lighting system is at 10% output, it is automatically turned off.

Shading system. We decided not to include the shades in the final DR control strategy. There are two major reasons for this recommendation. First, shades are being controlled for glare and direct sunlight and if left alone during a DR event, they will continue to maximize daylight, reduce solar gains by limiting direct sunlight, and prevent glare. Second, since the outside of the shades is dark, closing them off fully may increase heat gain. LBNL asked that the impact of the dark material be evaluated during the simulations of DR strategies to assess the solar gain associated with the material choice.

DR Simulations

This energy simulation study is probably the first in which an hourly model is used to evaluate dynamic DR control strategies during a new construction design process. A custom version of EnergyPlus (version 1.2.3.023) was written by NaturalWorks and utilized as the simulation engine. Figure 3 is a typical floor plan of a tower floor with usable area of 19,000 ft^2. The zones in the figure are identified by NaturalWorks for their simulations. The sizes of these zones vary from about 1,500 ft^2 to 300 ft^2.

Figure 3. Typical Floor Plan

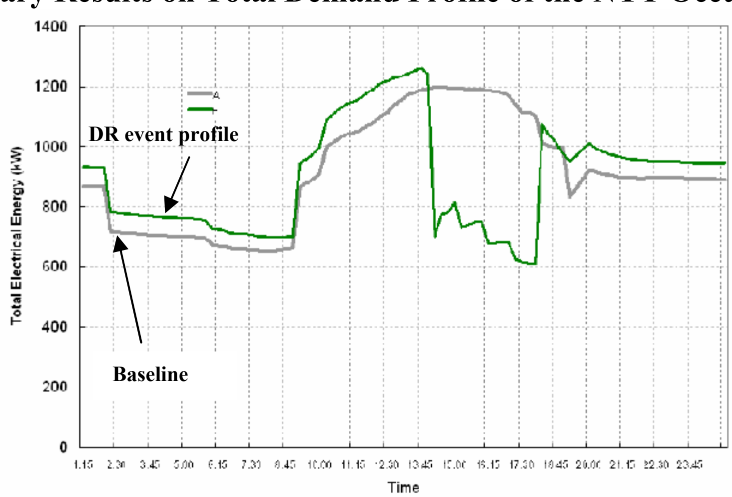


(Source: NaturalWorks Simulations (Carrilho da Graca et.al. 2005))

The modeling and simulation effort was conducted by NaturalWorks in two phases that involved some iteration. In the first phase, a basic building model was developed and a limited set of DR strategies were implemented such as shade control and global set point adjustment. However, the building model was not complete. The owner and LBNL researchers assisted in providing better estimation of values to refine the building model for simulations. During Phase II, NaturalWorks delivered a more complete building model including the ability to simulate lighting shedding strategies. For lighting management during DR events, the space is divided into three zones considering use and daylight availability: core, interior and perimeter. Two strategies for the lighting system, two levels for temperature set up and two addition HVAC strategies, one increasing the supply air temperature and the other reducing the capacity of fans boxes in the perimeter were assembled for simulations. DR sequences combining these six DR strategies were simulated by NaturalWorks.

Figure 4 displays the preliminary results from simulations underway in early 2006. The figure shows the baseline with overnight pre-cooling and the demand profile of the NYT under the best DR sequence. Although the demand savings is shown to be about 600 kW, since the simulations were not complete at the time this paper was written, LBNL chose a more conservative demand savings of 400 kW for the financial analysis. Occupant comfort under these sequences is still not understood. Therefore, it is recommended that the set points are made available to the building operators so that the sequences can be tested and refined during commissioning.

Figure 4. Preliminary Results on Total Demand Profile of the NYT Occupied Tower Floors



(Source: NaturalWorks simulations**)**

The owner has to decide how aggressively the DR strategies will be implemented. The current simulation results display potential demand savings but do not provide any comfort indicators. NaturalWorks is planning to examine predicted mean vote (PMV) and temperatures in the building in the future that will provide indicators of conditions in the space with various sequences of operations.

Pre-cooling may increase total energy consumption, but help reduce peak demands. Research in California has shown that operating a building slightly cooler in the morning and warmer in the afternoon can significantly minimize electric-peak demand while maintaining comfort (Xu et al, 2004). A New York-based energy services company suggested that since pre-cooling increases the morning baseline and the electricity price is \$0.16/kWh between 9 am and 11 am and increases to \$0.50/kWh in the afternoon, any pre-cooling done in the morning becomes additional earnings in the afternoon. This savings is related to the methods used in New York to calculate demand response baselines. The pre-cooling strategy developed for the initial simulations need to be further refined and analyzed. There is also some uncertainty about how pre-cooling performs with underfloor HVAC which in theory such a system may be an excellent candidate for pre-cooling, but more work is needed to understand how it will operate in practice.

Often when a building EMCS is evaluated to implement DR strategies, additional energy efficiency and peak load management benefits are realized through the exercise. The analyst developing DR strategies has to evaluate the building control strategies and this process may lead to identification of energy saving operational improvements like the retro-commissioning process. In the case of the NYT, the DR simulation analysis also resulted in identifying additional energy efficiency measures. Analysis of the position of the shades showed that the selected internal shading material was causing extra heat gain.

NY Times DR Economic Scenarios

This section summarizes the financial impact of 400 kW of demand reduction over four hours in The NYT building. Although the simulations identified 600 kW as potential demand reduction, a more conservative demand reduction of 400 kW is chosen for the financial analysis because of baseline related issues and simulation assumptions. A reduction of 400 kW results in a demand reduction intensity of approximately 0.9 W/ft^2.

The amount of financial savings will depend on the financial structure of these programs available from the local utility and the NY Independent System Operator (NYISO). Consolidated Edison offers five DR programs to its customers. Two of these programs are NYISO programs and are exclusive of each other. The DR programs available to The NYT through Consolidated Edison are summarized in Table 3.

Table 3. Summary of DR Programs Offered by Consolidated Edison

Program	Notification	Enrollment Period	Duration	Required Shed	Incentive
Independent Capacity Program (ICAP) - NYISO	Day ahead	Summer (5/1-10/31) Winter (11/1-4/30)	Min. 4 hrs.	Min. 100kW	\$6.68/kW of Unforced Capacity + energy payment of no more than \$0.5/kWh
Emergency DR Program (EDRP) - NYISO	Min. 2 hr.	1 year	Min. 4 hrs.	Min. 100kW	\$0.45/ kWh or 90% of price of energy in the real-time wholesale market
Distribution Load Relief Program (DLRP) - Con Ed	Min. 30 minutes	1 year	Min. 4 hrs.	Min. 50kW for 4 hrs.	\$0.45/ kWh or 90% of price of energy in the real-time wholesale market
Day-Ahead Demand Reduction Program (DADRP) NYISO	Day ahead	1 year	Variable	Variable	Customers are paid at least the forecasted price of electricity which will not be less than \$.05 for each kilowatt-hour curtailed
Voluntary Real Time Pricing Program (VRTP) –Con Ed	Day ahead	1year	Not Applicable	No pre-required shed	Real time prices are the only incentive/disincentive for customers

New York has had demand response programs for 5 years since the NYISO launched its DR programs in 2001. In recent years, New York State Public Service Commission has been moving towards requiring mandatory real-time pricing which may apply to Consolidated Edison's (ConEd) "Service Classification 4" customers. Since The NYT will be a ConEd customer under SC4, this regulatory decision directly applies to The NYT.

The current motivation for the NYT to participate in DR is to provide load relief to the electric grid for emergencies and to improve overall reliability. DR control sequences are being created to provide this load relief. If real-time pricing (RTP) is mandatory, the NYT may want to consider daily peak load management and RTP response strategies as well. The current EnergyPlus models can help evaluate predicted mean vote (PMV) and indoor temperatures that provide information for decision making related to occupant health, comfort and satisfaction.

Mandatory RTP. There are five programs offered to ConEd customers summarized in Table 3. Three of these programs are NYISO programs and two are offered by ConEd. If RTP is mandatory, Voluntary RTP (VRTP) offered by ConEd and Day Ahead DR Program (DADRP) offered by NYISO will disappear. DADRP is a form of VRTP.

Historical data on the frequency and duration of DR events were collected to develop estimates of the potential NYT DR program savings. Table 4 shows the frequency of dispatch for three of the programs. Next, this historical data were used to make assumptions for frequency of dispatch for the coming year and used for the calculations to predict annual savings in Table 5. Of the two NYISO programs, ICAP is the more lucrative one for The NYT because in addition to the demand savings at $0.50/kWh, it pays a predetermined capacity payment monthly. Last season this was $6.68/kW that would result in a $2600 monthly payment to the NYT should the NYT deliver 400 kW of demand reduction. In addition, if The NYT can reduce 400kW over 4 hrs, it can receive an approximate savings of $800 per event. Table 4 shows that this program was called once in 2005 for three hours and twice in 2002 for four hours each. The NYT can participate in this program every season and needs to deliver the promised amount every time it is dispatched during this period.

Table 4. Frequency of Dispatch

Program	Frequency of Dispatch			
	2005	*2004*	*2003*	*2002*
ICAP	1	NA	NA	2 in summer 1 in winter
EDRP	1	0	2	4
DLRP	9	NA	NA	NA

Table 5. Predicted Annual Savings

Program	Predicted Annual Savings*
ICAP	$17,632.00
EDRP	$1,440.00
DLRP	$1,600.00

* Assuming two dispatches with 400 kW demand reduction each time.

The other NYISO program, Emergency DR Program (EDRP), works similar to ICAP but does not pay a monthly fee for the promised savings. Participants are expected, though not obligated, to either reduce electricity consumption and/or transfer load to an onsite generator for a minimum of four hours. The expected incentive for an EDRP event for 400kW demand reduction over 4 hours is $720.

These two NYISO programs are mutually exclusive; therefore customers cannot participate in both programs at the same time. In addition, customers participating in ICAP cannot also participate in DLRP.

RTP not mandatory. If RTP is not mandatory this year, given the afore-mentioned options, ICAP and DADRP participation may be beneficial to the NY Times. The goal of ICAP, which is to increase the reliability of the electric grid when there are constraints, is similar to the goals of the NYT and yields the most lucrative savings. In addition, The NYT may want to participate in the DADRP program to experience RTP at its own pace. DADRP is designed such that the next day's hourly prices are published a day ahead and the customers decide to participate or opt out of the program daily.

Under an RTP scenario, for example with the DADRP, a customer is paid at least the forecasted price of electricity or at least a minimum of $0.05 per kW that is bid and delivered as savings. Using 2005 NYISO's Day Ahead market location-based marginal pricing system and assuming a minimum increase of prices over a preset threshold of $0.25, the established threshold is exceeded five times over the summer in 2005. Since the limiting factor is the price of electricity, the duration of the shed depends on the duration of the price over the threshold. In 2005, the total duration of the price over the selected threshold was approximately 36 hours. If the NY Times participated in the DADRP in every hour with a 400 kW demand reduction, it would save a total of approximately $7,200.

Results and Recommendations

The Energy Plus simulations provide a rough estimate of the DR potential of the building. The goal is to apply the lessons-learned from the theory of simulations to the practice of real systems. The lighting and HVAC system designers will develop specifications for controls where each of the suggested strategies can be implemented and tested within the actual building. Lighting controls will allow for customized floor-by-floor and zone by zone application of relative light dimming either by actual decrease of the dimming level or by allowing to decrease the target set point of a zone from a central location. An additional feature that will allow for implementing a target kW reduction will also be programmed into the system. Once tested, demand response stages 1 and 2 icons should be provided to the building operator for semi-automatic DR controls. On the HVAC controls side, a DR interface will be developed for initial testing of the temperature increase in zones, easy access to supply air temperature set up for pre-cooling and reducing the capacity of fan boxes on each floor by orientation. Once the systems are commissioned and the DR strategies are tested, the financial impact should be re-evaluated since the actual savings can be better estimated and programs and incentives may change.

Future Research

This research project has demonstrated that DR strategies can be developed with new advanced controls, such as those in the new New York Times building. Although the peak demand of the building is estimated, DR strategy results should be verified after the building is operational. The DR sequences have to be tested in the occupied building and their effect on the occupant comfort should be measured. A set of commissioning tests for DR strategies will be developed. In the past, LBNL collected trend logs and energy information during a DR event and analyzed these results to evaluate DR strategies. Development of a similar method specific to the NYT building is required to verify DR operations.

In a more general sense, the exploration of building controls in the NYT building raised necessity of a master control concept. Flexible employee schedules, telecommuting options, organizational flexibility concepts have changed the use of commercial buildings. The changes in the organizations have been realized in building operations levels. Building operators schedule multiple modes of operations changing within the floors of the same building, within days, weeks and seasons. The NYT building currently has the following operational modes:

- Occupied/Unoccupied,
- Maintenance/Cleaning,
- Warm up/Cool down,
- Night purge.

DR strategies, programmed into various DR sequences, will be added to the control system as a separate mode and the building operator will only have to decide between the provided modes using semi-automatic demand response. However, under a potential future envisioned master controls concept, each DR strategy would be implemented not just as an optimized sequence of operations, but as needed with financial feedback from the utility and energy performance feedback from the building allowing for decision making with available short-term information. This envisioned future requires research on control algorithms that can accommodate outside signals on the building controls side as well as research on communication methods that allow the building to be directly connected to the electric grid.

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