Peak Demand Limiting in New York Residential Housing: Automatic Air Conditioner Load Curtailment and Demand Limiting Using Wireless Mesh Communications

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ABSTRACT

This paper presents the results of a project to demonstrate that fleet management of residential apartment air conditioning units can limit the electrical demand measured at a building master meter and achieve a cost savings without complaint from the residents. A building energy management system integrated a wireless mesh network and air conditioning (AC) unit controllers was installed in a 99-unit residential supportive housing building in New York City. A customized control algorithm was implemented to switch AC units in a temperature prioritized, intelligent, fashion to maintain predefined demand limits at the building master meter. The system also performed a load curtailment event test to simulate a response to an Independent Service Operator (ISO) curtailment event. The test description, results, and analysis are presented in this report.

The energy management system operated over a complete billing period in the summer of 2005 to reduce the monthly peak demand by 46 kW, or 15% of projected peak, and yielded an estimated savings of $1150. A smaller avoidance in energy charge was also realized but not calculated. The load curtailment event test achieved a curtailment of 20kW, or 8% of building demand, over a two-hour period.

The test results are utilized to discuss an economic strategy that trades off savings realized from operation under a daily demand limiting regime verses the potential revenue from responding to an ISO curtailment event.

Introduction

The Association for Energy Affordability (AEA), in partnership with the New York State Research and Development Authority (NYSERDA), and Intech21 Incorporated, designed and operated a demonstration project of a wireless, web-based, energy management system in a residential building to control individual air conditioning units. A wireless-mesh enabled Direct Load Control (DLC) unit was installed inside the housing of each Packaged Terminal Air Conditioner (PTAC). The PTACs were sized between 9,000 and 20,000 BTU. The DLC units formed a wireless mesh network to allow two-way communications with the E-Master Energy Management System (E-EMS). The E-EMS executed the Peak Demand Limiting (PDL) algorithm to switch individual PTACs off and on, via the DLC units, to attain the desired electrical demand level measured at the single electrical master meter for the building.

New York's electricity market is partially deregulated allowing for purchase of capacity and energy by competitive energy service companies (ESCO). The market typically charges large consumers of power (i.e., over 10kW peak) not only for the energy usage in kWh, but also for the maximum demand recorded each month in kW. Large consumers of power can also subscribe to participate in a well-established New York Independent Service Operator (NY ISO) demand response program that pays for curtailments in demand during declared emergency conditions. These economic forces encourage large customers to manage demand.

Many residential buildings in the area, like the project building, are "master metered" with the owner paying one large electric bill incorporating the load from all the apartments including all the resident AC units. Typically the AC units in master metered buildings are over-utilized since the resident does not pay the electric bill.

The goals of the project were three fold: 1) to demonstrate that a residential building with electric air conditioning can reliably manage its demand load to limit the maximum demand charge incurred each month at the master meter; 2) to participate in a load curtailment program; and 3) accomplish 1) and 2) without the resident's ability to override the control while minimizing complaints from the residents despite the lack of control.

Building Description

The 33-floor building had 99 apartments and approximately 300 PTAC units. There were 1, 2, and 3 bedroom apartments with 2 – 5 PTACs per apartment. The apartments were not sub metered. The building management paid for electricity usage for all residents based on a single master meter.

The building, located on a southwest-facing corner, experienced a high solar gain in the afternoon leading to a typical monthly summer peak demand of 300 kW to 350 kW. The base load of the building[1] was approximately 100 kW. Thus the average air conditioning peak demand was 2 to 2.5 kW above the base load for each apartment in the building.

An Energy Service Company (ESCO) supplied energy measured at the master meter. The master meter was an advanced interval meter that provided demand and energy information by a pulse output at 5-minute intervals to the E-EMS.

The building was supportive housing and the management was a non-profit corporation. All electric bill savings in the form of avoided costs were returned to the residence in some form.

Market Description

The building management had to pay for each kW of the monthly maximum demand as well as the monthly energy usage in kWh as is typical for customers of this size.

The Consolidated Edison Utility (Con-Ed) read the master meter each month and recorded the monthly maximum demand and monthly energy usage. All parties used this data for settlement. Con-Ed charged for transmission and distribution of the electricity. The ESCO supplied the energy commodity charge. The Con-Ed transmission and distribution rate for electrical demand in the summer is approximately 15$ per kW. The pricing structure of the ESCO is complicated and obscures the total cost per kW of demand. A general number used for the total cost of demand during the summer was 25$ per kW.

The NY ISO runs a load curtailment program that rewards customers who can shed a minimum of 100kW of load when curtailment events are called. These events are typically once or twice per summer, for a four hour period. For the purposes of this demonstration project the building was partnered with other buildings to aggregate into a 100kW block through registration

[1] Based on winter observations of the master meter demand. The building has oil fired steam boiler heating.

with a curtailment agency. The specific program was the Emergency Demand Reduction Program that permits participation without penalty for not curtailing.

Wireless Energy Management System

The E-Master Energy Management System (E-EMS) is a web-based application that utilizes a SQL database to store data and process control calculations. Control and monitoring are done through a web-browser graphical user interface. The E-EMS controls the DLC units located at the individual PTAC units and provides temperature trend data, delimited output files, and demand and usage information for each apartment.

A wireless communication system was selected for the communications backbone for the control and monitoring points. This meant that the prohibitively high cost of hard wiring the control units was avoided plus the demonstration and evaluation of wireless mesh in control applications was gained. Wireless mesh topologies provide a great advantage in this regard allowing simple, cost effective installation of the controlling units. A drawback, however, with wireless mesh units is reliability of communications. There are further advantages and disadvantages to wireless mesh communications (Kintner-Meyer M, MR Brambley, TA Carlon, and NN Bauman. 2002). The DLC units consisted of a relay with on-board logic that measures a temperature and performs a thermostat function with the relay in a heating or cooling mode. In the cooling mode, the relay interrupted power to the PTAC when the temperature was below the set point, including a small dead band. All parameters were adjustable and the DLC unit would operate without communication from the E-EMS.

A wireless power meter measured the temperature, electrical usage, and demand in each apartment. All DLC and power meter data were recorded every 15 minutes by the E-EMS.

Control Strategy

The demonstration project measure of cost effectiveness was to save money for the building under normal power pricing conditions and provide the capacity to earn money during incentive periods. The two strategies are employed to do this are:

Manually set a peak demand limit based on billing history. Leave this limit in place for the entire billing period and allow the Peak Demand Limiting (PDL) algorithm to automatically curtail demand to hold the limit.

Enable the building to participate in demand response programs by curtailing demand when alerted of an event. Curtailment can still occur when (1) is active.

Curtailments were achieved by manually setting the PDL to a limit that was below the current building demand. The PDL would achieve and hold the limit and create a curtailment relative to the normally increasing demand of an uncontrolled demand profile.

PDL Control Algorithm

The PDL algorithm used a set point increase to switch off the DLC relay. In this way the PTAC would still operate if the DLC unit did not receive the message to return the set point to normal.

The PDL algorithm was developed within the framework of the E-EMS application. The PDL operated continuously in the background monitoring the building demand and began to select units to curtail when the demand approached the demand limit. A simple proportional-integral calculation determined the number of units at each interval the building demand was checked. At each interval a “shed list” of units available for the PDL was prepared and prioritized by the difference between the current temperature and the set point to ensure that the most comfortable residents were selected first.

The control screen for the PDL limiting allows for control parameters to be changed. The user was able to change:

- The Refresh Rate – The interval duration between the shed lists.
- The Zone Set Point Adjustment– The amount that the set point of the thermostat on the DLC is changed (expressed as a multiplier of the dead band).
- Manual Demand Limit – The desired limit at the master meter, in kW.
- PDL Activation Constant – The percent of the demand limit that triggers activation of the PDL algorithm.
- Shed Load – in kW. The number of kW that each unit is estimated to contribute to the overall amount curtailed by the shed list.

Figure 1. PDL Settings Screen on the E-EMS Graphical User Interface Courtesy of Intech21, Inc.

Control Effect for the Resident

In the apartment the resident would notice the unit switch completely off for a short period, typically 23 minutes. The PDL did not allow a unit to be selected for two successive shed lists. Notably the DLC unit switches the PTAC completely off, not just the compressor. This regimen increases the yield in kW savings per unit but the shutoff was noticeable to some residents.

Subsequent projects will integrate control into the unit so that the compressor can be switched off while the fan is left on. This will greatly increase the ability to switch off without resident notice.

Test Procedure and Performance Metrics

Tests were conducted throughout the summer of 2005, a very hot summer relative to the 30 year Cooling Degree Day (CDD) data. The total CCDs for 2005 were 25% higher than that of 2004. In addition, the CDD in each month of 2005 were higher than the corresponding month of 2004 and, each month of 2005 experienced a higher temperature maximum within the month compared to 2004. This data comparison supports the baseline assumption that the maximum building demand for each summer month would exceed that of 2004. No significant physical changes were made to the building between 2004 and 2005 that might contribute to significantly different performance versus temperature or CDD.

The testing was begun on July 31, 2005 and continued to September 22, 2005. The billing period used for analysis began August 23 and ended September 23, 2005. A manual limit of 300 kW was set for the period from July 31 to August 22 but since this did not include a full billing cycle it is included only to further demonstrate the method.

On August 23 the August-September billing period began. The limit was set to 245 kW on August 22 for this billing period. This was selected to yield a savings compared to past years' performance. The 2004 demand peak was 260 kW for the same billing period.

The avoided demand was calculated in two ways, (1) Data for 2005 days where the PDL did not activate was used to create a relationship between outdoor temperature and building demand. The relationship is roughly linear. A second order relationship between outdoor temperature and building demand was also made, (2) the billing data for the previous 3 years was examined and compared this with maximum temperature recorded at the Central Park NOAA station during the billing period. This relationship is also roughly linear.

The avoided demand on PDL days for July 31 to August 22 was calculated using method (1) only.

The economic benefit of avoided demand was set at $25 per kW. For curtailment comparisons the number of $55 per kW was used.

Results: Monthly Peak Demand Limiting

The PDL ran continuously as a process in the background and would activate automatically in response to the building demand. The PDL did not activate every day. A typical PDL response is shown in Figure 2 for a 24-hour day. Note that the demand during the day is reflecting the normal residential curve for AC load where the peak occurs around 4:00 - 8:00 PM until it is limited by the PDL. Figure 2 shows that as the outdoor temperature continued to increase the demand was halted by the actions of the PDL at 12:00 PM when the manual limit of 245 kW was reached.

Figure 3 shows the building demand during a 24-hour period where the PDL was not active. Note how the demand "follows" the outdoor temperature in Figure 3 but is limited in Figure 2.

Figure 2. Building Demand vs. Temperature on 8-31-2005 With PDL Active

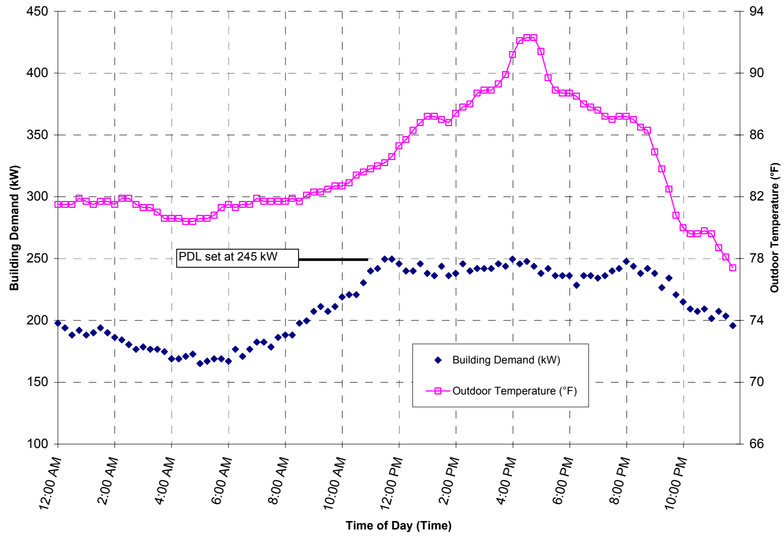


Figure 3. Building Demand vs. Temperature on 7-22-2005 With PDL Not Active

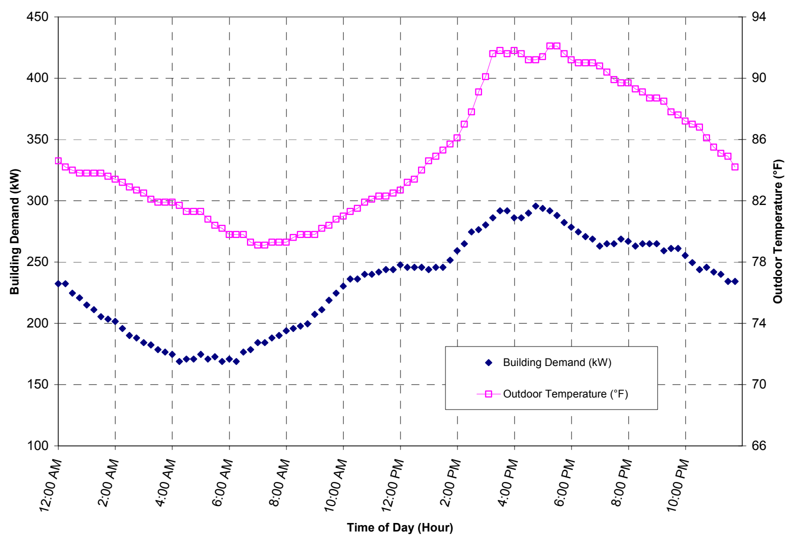


Table 1 shows the days during the test period where the PDL was activated to limit a significant demand peak. Note that on 8/22/2005 the limit was lowered to 245 kW for the beginning of the August-September billing period.

Each PDL event also resulted in a savings due to the avoided kWh usage but the usage savings is small compared to the avoided demand savings as shown in Table 3.

For the August-September billing period the peak demand limit was set to 245 kW. The maximum demand recorded by the E-EMS during this period was 259.2 kW and the maximum demand on the Con Edison bill was 260 kW.

The difference between the desired demand limit and the measured and billed maximum demand reflects the rapid fluctuations in the noisy demand measurement. The PDL samples to determine activation at the refresh rate, or every 20–25 minutes, and during this time the building demand can change by +/- 20 kW.

The avoided maximum can be taken directly from Table 1 but it can also be estimated from the past summer billing data. The analysis methods are described in the section entitled Test Procedure and Performance Metrics.

Table 2 shows the results of these calculations. The number chosen for the avoided kW is the average of all the methods and is 46 kW or 15% of the total projected load for the August-September billing period.

Table 1. Significant PDL Activity During the Entire Test Period from 8-1-2005 through 9-22-2005

Date	Limit (kW)	Max Recorded Peak During Day (kW)	Calculated Avoided Peak (kW)	Difference (kW)	Approximate PDL Event Duration (hours)	Percent of Avoided Demand (%)
8/5/2005	300	305	345	40	4	11.6
8/12/2005	300	300	325	25	9	7.7
8/13/2005	300	305	352	47	9	13.4
8/14/2005	300	305	330	25	6	7.6
8/22/2005	245	253	274	20	4.5	7.3
8/31/2005	245	259	281	22	8.5	7.8
9/2/2005	245	253	274	20	3	7.3
9/12/2005	245	259.2	286	27	2	9.4
9/13/2005	245	259	306	46	9	15.0

Table 2. Results of Avoided kW from the Monthly Maximum Demand for Aug-Sept Billing Period

Calculation Method	Con-Ed Bill Analysis	1st Order Temperature Correlation	2nd order Temperature Correlation	Average All Methods
Avoided Demand (kW)	55	47.7	35.5	46

Table 3. Estimated Savings from Avoided kW and kWh for the Aug-Sept Billing Period

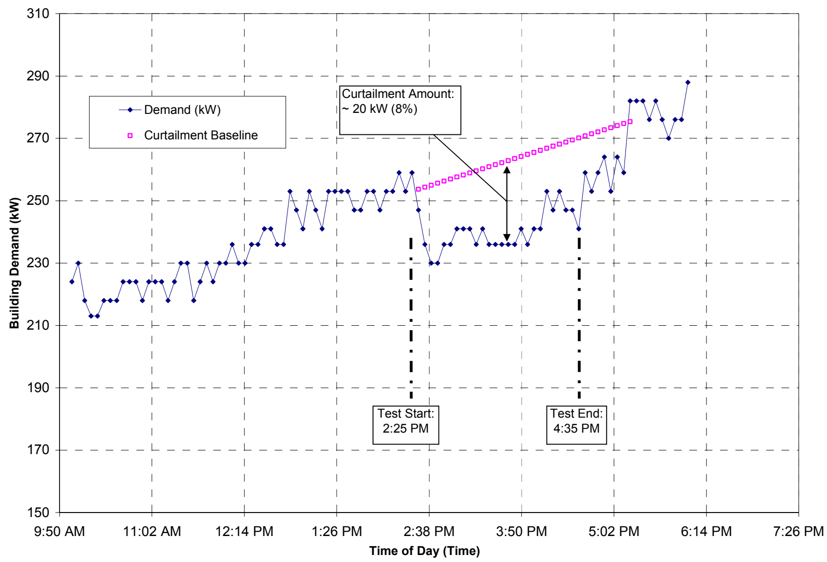
	Unit Amount	Savings per Unit	Total
Demand	46 kW	$25.00	$1150.00
Usage	384 kWh	$0.10	$38.40

Results: Load Curtailment

There was only one demonstration, not utility imposed, curtailment test. The duration was 2 hours. A modest curtailment of 10% was attempted. The curtailment was achieved by observing the electrical demand at the master meter and setting the PDL manual limit to a value below the current demand.

Figure 4 shows curtailment response of the electrical demand in kW every 5 minutes as measured at the master meter. The curtailment was created by choosing a manual PDL limit that was 25 kW less than the 250 kW of the building demand observed at the start of the test. Note the building continues to heat up during the test and the demand increases between 4:00 and 4:30PM. The PDL increases its curtailment to maintain the limit which is achieved just before the test is ended at 4:35 PM.

Figure 4. Demand vs. Time for the Curtailment Test Using the PDL



Note the curtailment does not end abruptly but is slowly returned to the normal demand to minimize overshoot peaks. There may be a slight overshoot noticeable from 5:15PM to 5:35PM but it is not easily discernable from the noise of the demand measurement.

The yield from the curtailment test is estimated at 20 kW, or 8%, over the 2 hour duration.

Results: Economics of Limiting vs. Curtailment Strategy

A simple economic analysis can compare the benefit of daily demand limiting versus the potential benefit of participating in a load curtailment event. There are several assumptions in this analysis.

- The baseline demand used for curtailment is an average of the peak demand of the four summer months from the previous year.
- Only one curtailment event may be called and it would occur in the July-Aug billing period.
- The limiting function was used during 3 of the billing periods at a level of 15% of the monthly maximum peak.
- There is a trade-off between limiting and curtailment so that the amount of limiting and curtailment will total 15% of the demand and that an increase in one results in a decrease of the other.
- Curtailment is assumed to be worth 55$ per kW and limiting is worth 25$ per kW.

A general assessment of the risks associated with different strategies is included in Table 3. It is not certain that a curtailment event will be called in a given year. The risk level reflects the economic strategy that the building is taking by forgoing the limiting benefit to potentially receive the higher curtailment benefit.

Table 3 examines three strategies:

1. Limit 15% - The PDL limits the demand at 15% in all four billing periods.
2. Limit 15%, Curtail 15% - The PDL limits the demand in three of the billing periods at 15%. In July-Aug the limit is set to 7.5% and the curtailment is attempted at 7.5%.
3. Curtail 15% - The PDL limits the demand in three billing periods at 15% and set no limit for the July-Aug billing period. The curtailment in July-Aug is attempted at 15%.

Table 3. Curtailment vs. Limiting Analysis Results

		Benefit ($) Limiting/Curtailment				Total Benefit ($)	
		May-June	June-July	July-Aug	Aug-Sept		
Max Demand (kW)		312 kW	332 kW	352 kW	307* kW		
Strategy	Risk					Curtail Event "Yes"	Curtail Event "No"
1	Low	$1,170	$1,245	$1,320	$1,150	$4,885	$4,885
2	Med	$1,170	$1,245	$660 / $2,112	$1,150	$5,677	$4,225
3	High	$1,170	$1,245	0 / $2,904	$1,150	$6,469	$3,565

*From Table 1

Analysis

The results of the project demonstrated the ability of the PDL to automatically shave the monthly maximum peak by setting a manual limit. The demand limit will save the building money by avoiding demand charges that are around 25$ per kW. The results indicate that 15% of the monthly demand can be shaved in the summer months. The highest savings may be possible in the July-August billing period when more kW are used for air conditioning and users are subject to load control.

During this test approximately 45 of the 300 load control devices were not participating in the testing due to communication problems, malfunction, or the comfort of certain residents with special needs. These 45 devices represent 15% of the total population or an estimated 38 kW of AC load. The avoided demand savings would certainly be improved if these devices were included.

There were no resident complaints during the testing period. Residents were informed of the energy management system by the on-site building manager though no formal training was conducted.

The most notable drawback to the current switching method is that the DLC unit cuts power to the entire unit including both the fan and compressor. A superior, and much less noticeable, demand limiting method would leave the fan operating while the compressor was switched off. This approach is being explored for a future project with several PTAC manufacturers.

The results show that the PDL works to keep the demand below a certain limit. The building demand at the master meter is measured every five minutes however the PDL sampling interval, which is the same as the refresh rate, occurred at longer intervals. Thus if the demand at the master meter at one refresh interval is 240 kW the PDL does not activate. In the next 15 minutes the demand may increase to 260 kW before the PDL finally "sees" the increased demand and initiates load shedding. This effect produced the 260 kW maximum monthly peak for the Aug-September billing period when the limit was set at 245. This problem can be addressed by increasing the rate at which the PDL looks at the demand to decide on PDL initiation. Also, the activation constant can be reduced to lower the height of the incidental peaks.

Wireless communications used in critical control applications require that the communications be very reliable. Considerations were made in the PDL control logic to eliminate errors due to miscommunication. For example any device that did not have a perfect communications record for the trailing hour was excluded from the shed list as well as any device that had a command waiting to execute.

The PDL relies on maintaining good communications between units. The economic risk of technical failure was not examined but would be a concern especially in load curtailment where penalties for non-compliance may occur.

The simple economic analysis reveals that the building can use the demand limiting function in conjunction with benefits of utility curtailment directives. The employment of a combination of limiting and curtailment strategies can be analyzed in more detail to make a final decision, but the path of selecting partial curtailment and partial limiting probably offers the best mix of risk and benefit.

Conclusions

The application of an intelligent switching algorithm to control electrical demand in residential multi-family buildings is possible. The project demonstrated that load limiting and load curtailment can be done reliably and that the limiting can reduce the monthly summer maximum demand by at least 15%.

Under the circumstances of this project, the demand limiting and curtailment can be carried out without resident complaint. Further incorporation of the device to switch the compressor only would improve the aesthetic operation of the system.

Wireless mesh based energy management systems can be utilized successfully in two-way control and monitoring applications. Special considerations are necessary to minimize the effect of communication reliability errors.

A simple economic analysis of this building shows that a combination of demand limiting and curtailment will provide the best opportunity for savings with mitigated risk of non-payment.

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