# Using Product Portfolios to Increase the Value of Customer-Sited PV [1]

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## Introduction

The financial community has long recognized that the value of a portfolio of assets (e.g., stocks, bonds) can exceed the value of an individual asset. This is true because portfolios can be constructed to provide superior expected returns with the same amount of risk or the same expected returns with a lower risk than individual assets. The task of portfolio construction is to select the correct assets in the correct quantity.

This same general principal applies when one moves from financial markets to physical product bundles. That is, it is possible to construct a portfolio of physical products such that its value exceeds the value of the products when valued individually. The task of portfolio construction is to select the correct products in the correct sizes.

Commercial customer-sited PV represents a valuable sector for PV deployment for a variety of reasons. First, customer-sited applications benefit from retail energy rates. Second, the high PV/ load correlation leads to demand reduction at retail demand rates. Third, commercial operators can take advantage of local and national financial benefits available to businesses.

It has also been shown that value of a PV system can be further increased by constructing a portfolio of products. For example, Perez, et. al. [ 1 ] have shown that the value of a PV/solar load controller (SLC) portfolio often exceeds the value of each of these technologies when examined independently. It is also believed that on-site PV generation may enhance the effectiveness of uninterruptible power supplies (UPS) when such systems are needed.

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# Objective

This paper has several objectives.

1. Identify modifications to the Clean Power Estimator software program to estimate the value of added demand reduction (through use of the SLC) and enhanced UPS efficacy when they are included in a portfolio of products that include PV.
2. Perform the evaluation using a minimal amount of load and PV output data. In particular, the goal is to estimate the value using only sample load profiles and basic PV output data.
3. Validate the accuracy of the model as compared to measured building load and PV output data.

# Solar Load Controller (SLC)

## *Introduction*

The good correlation between PV output and building loads leads to demand reduction at retail demand rates. This correlation, however, is not perfect. Since demand charges are assessed based on the highest load during some time period, a cloud passing over the PV system during a peak load could substantially reduce the demand reduction provided by the PV system.

One remedy is to include a device called a solar load controller (SLC) with the PV system. This solution is attractive, because, as shown in Figure 1, there is a strong correlation between building load and temperature. Furthermore, if we examine the relationship during the summer months (June, July, Aug, Sep), there is a strong time of day/day of week component to the relationship as well (see Figure 2)

The SLC acts upon building load by resetting the building's cooling set point temperature. The building user selects an allowable amount of end-use temperature adjustment discomfort to evaluate the corresponding increase in PV demand reduction. Thermostat setting adjustment during the cooling season is an effective means of implementing solar load control. Such SLC prototype applications have already been carried out with satisfactory results [ 1 ].

The goal of the SLC is to enhance peak demand reduction by mitigating end-use load drivers in response to critical load/temperature situations. As shown in Figure 3, the SLC enhances the natural correlation between solar energy availability and peak loads driven by commercial air conditioning. A small amount of load control (right) can substantially increase demand reduction achieved with PV alone (center) if conditions are not ideal (as shown left).

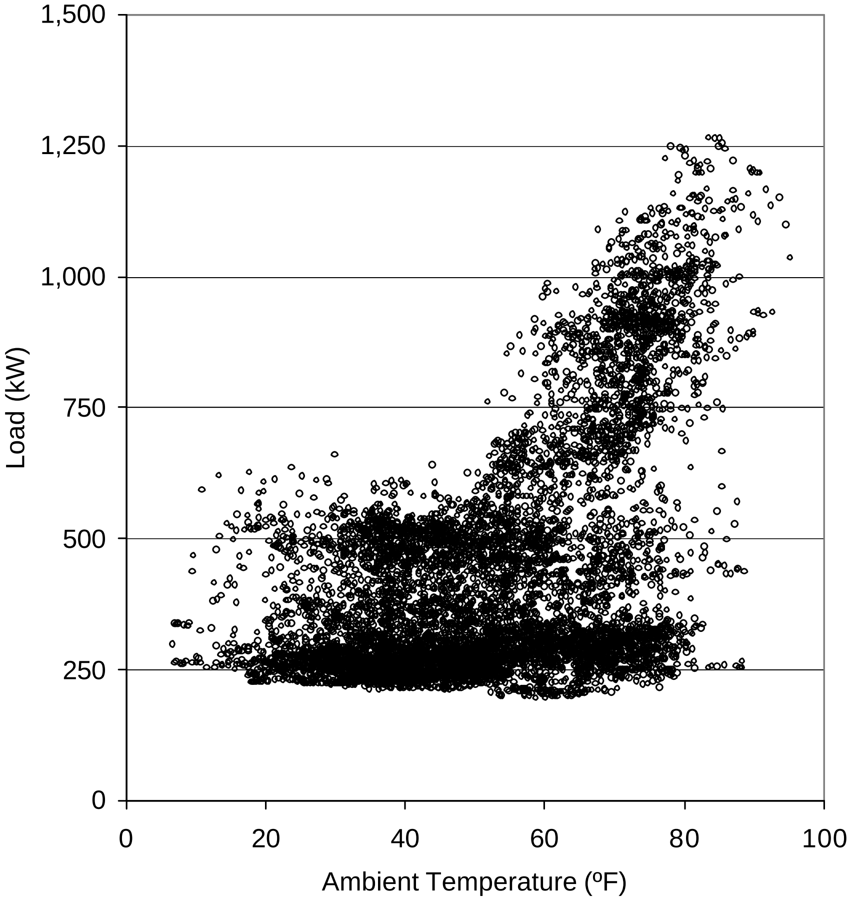


Figure 1. Building load versus ambient temperature (Westchester, NY 1993).

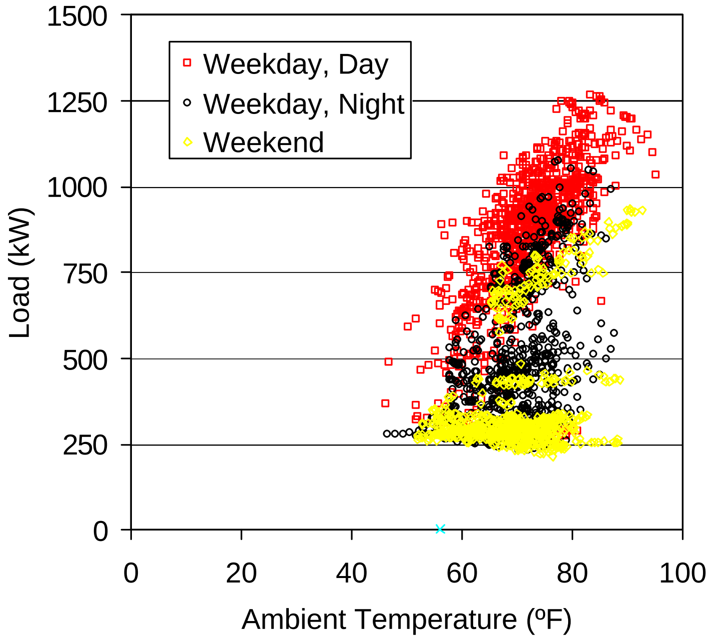


Figure 2. Building load in summer months (Westchester, NY 1993).

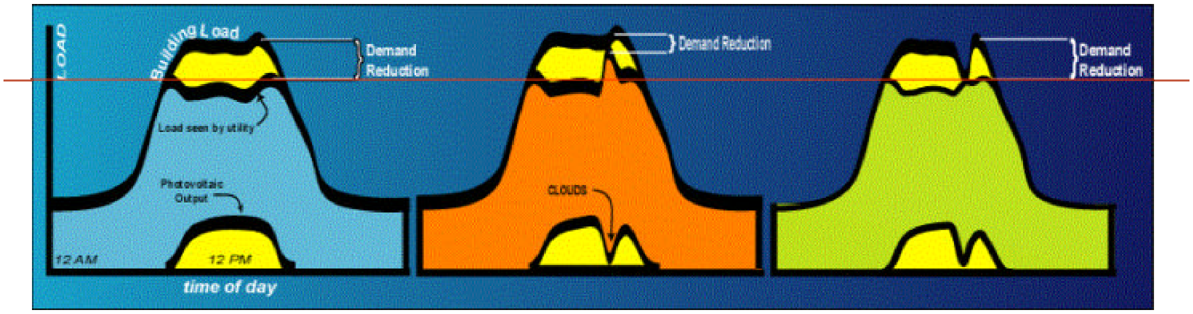


Figure 3. The solar load controller (SLC) can substantially increase demand reduction.

## *Methodology*

The Clean Power Estimator [ 2 ] version described in this paper focuses on this temperature-based type of load control. In addition to the standard CPE program inputs, the SLC-specific inputs to the program are:

1. The maximum discomfort (in one-day degree-hours temperature increase) the building occupant is willing to allow
2. A seasonal building load profile (defaults are available)
3. The building's cooling balance point (i.e., the outdoor temperature above which the building requires cooling) and
4. The building's load-temperature coefficient -- i.e., the load-temperature trend illustrated in Figure 1; this last input may be estimated from past bills by comparing highest summer demand and off-season demand.

Based on this set of inputs the program automatically calculates demand reduction. The effectiveness and value of load control may be gauged by running the program without the SLC and comparing results.

The calculations are based on site-specific 8760-hour [ 3 ] simulations. However, in order to minimize the web transfer of so many data points and to facilitate the generation of the hourly load data, the TMY data are first condensed to a set of 365 daily parameters. The data are then "re-inflated" on the user's computer. The condensed TMY-based information includes 365 daily values of (1) daily clearness index, (2) the ratio between daily clear-day global irradiance and daily clear day irradiance on the 15th day of each month, (3) the daily minimum temperature and (4) the daily temperature range.

On the host computer, the program generates hourly clearness indices from the daily values using a semi-statistical methodology [ 4 ] and hourly ambient temperatures derived from the daily minimum temperature and range following ASHRAE guidelines [ 5 ]. Hourly PV outputs are obtained by modulating the standard (12-months x 24-hours) average PV output tables generated within the CPE with the hourly clearness index.

In parallel, hourly building loads are generated via linear modulation of the reference building load profiles with hourly temperature (using the input load temperature coefficient specified above).

This condensed approach allows one to generate hourly output for arbitrary PV configurations "on the fly", along with time coincident building demand, using only a small number of transferred data.

Once hourly building load and PV outputs are available, the program calculates the PV monthly demand reduction, as well as the additional reduction made possible by the SLC if that option is selected.

## *Validation*

We compared SLC results obtained using measured building load data and time - coincident PV output simulated from actual co-located measurements against (1) the results obtained with the same data condensed and processed as explained above (i.e., load shapes + 365 insolation and temperature data points), and (2) against the results obtained using TMY data (note that the latter would represent the "generic" performance of the model). This approach allows us to individualize and quantify two sources of uncertainty in the model, i.e., (a) the data -condensation-expension algorithm and the load generator algorithm, and (b) the use of generic TMY data.

The Westchester County building in the New York City metropolitan area was selected for the validation. This building provided access to both building load data and nearby solar radiation measurements for the year 1993 [ 6 ]. This building exhibited a summer peak load of 1265 kW that year (see Table 1) while winter (non-cooling months) peak loads were less than 700 kW.

Table 2 illustrates results based on both actual and model data. The table presents the peak reduction achieved during each cooling season month for three PV system sizes (5%, 10%, and 20% of peak annual demand) with and without a SLC. The SLC is dispatched up to a maximum of 10 degree -hours of user discomfort per day. The rows labeled Actual are based on actual data. The rows labeled Estimate are based on a TMY data set. The rows labeled Estimate (1993) are based on data for 1993; the same year as the load data. The first two columns in

Table 3 present the value of the demand reduction with and without the SLC. The third column (and Figure 4) presents the incremental value provided by the SLC.

Table 1. Peak load.

| | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|
| Actual | 1,122 | 1,148 | 1,212 | 1,265 | 1,111 |
| Estimated | 1,025 | 1,074 | 1,055 | 887 | 824 |
| Estimated (1993) | 938 | 1,125 | 1,089 | 913 | 834 |

Table 2. Peak load reduction (kW) with various PV system sizes.
(10% load increase per ºC;10ºC per day allowable inconvenience when SLC is used)

| | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|
| Without SLC | | | | | |
| 63 $kW_{ac}$ PV | | | | | |
| Actual | 52 | 48 | 53 | 33 | 37 |
| Estimated | 54 | 40 | 58 | 39 | 23 |
| Estimated (1993) | 55 | 37 | 58 | 46 | 24 |
| 125 $kW_{ac}$ PV | | | | | |
| Actual | 90 | 79 | 82 | 66 | 70 |
| Estimated | 95 | 69 | 101 | 69 | 35 |
| Estimated (1993) | 88 | 73 | 112 | 91 | 39 |
| 250 $kW_{ac}$ PV | | | | | |
| Actual | 122 | 98 | 106 | 133 | 131 |
| Estimated | 151 | 112 | 147 | 72 | 58 |
| Estimated (1993) | 141 | 131 | 162 | 123 | 49 |
| With SLC | | | | | |
| 0 $kW_{ac}$ PV | | | | | |
| Actual | 77 | 94 | 77 | 86 | 120 |
| Estimated | 66 | 53 | 69 | 72 | 69 |
| Estimated (1993) | 83 | 78 | 74 | 61 | 47 |
| 63 $kW_{ac}$ PV | | | | | |
| Actual | 125 | 137 | 120 | 136 | 161 |
| Estimated | 115 | 90 | 110 | 114 | 92 |
| Estimated (1993) | 134 | 123 | 127 | 110 | 79 |
| 125 $kW_{ac}$ PV | | | | | |
| Actual | 169 | 171 | 162 | 178 | 203 |
| Estimated | 165 | 128 | 149 | 142 | 111 |
| Estimated (1993) | 179 | 163 | 178 | 156 | 103 |
| 250 $kW_{ac}$ PV | | | | | |
| Actual | 252 | 223 | 237 | 250 | 271 |
| Estimated | 250 | 195 | 221 | 166 | 140 |
| Estimated (1993) | 251 | 217 | 246 | 235 | 135 |

Table 3. Value of demand savings Value (based on $17.62/kW/month)

| | With SLC | Without SLC | Value of SLC |
|---|---|---|---|
| No PV | | | |
| Actual | $7,999 | $0 | $7,999 |
| Estimated | $5,797 | $0 | $5,797 |
| Estimated (1993) | $6,044 | $0 | $6,044 |
| 63 $kW_{ac}$ PV | | | |
| Actual | $11,964 | $3,929 | $8,035 |
| Estimated | $9,180 | $3,771 | $5,409 |
| Estimated (1993) | $10,096 | $3,876 | $6,220 |
| 125 $kW_{ac}$ PV | | | |
| Actual | $15,558 | $6,819 | $8,740 |
| Estimated | $12,246 | $6,502 | $5,744 |
| Estimated (1993) | $13,726 | $7,101 | $6,625 |
| 250 $kW_{ac}$ PV | | | |
| Actual | $21,725 | $10,396 | $11,330 |
| Estimated | $17,127 | $9,515 | $7,612 |
| Estimated (1993) | $19,100 | $10,678 | $8,422 |

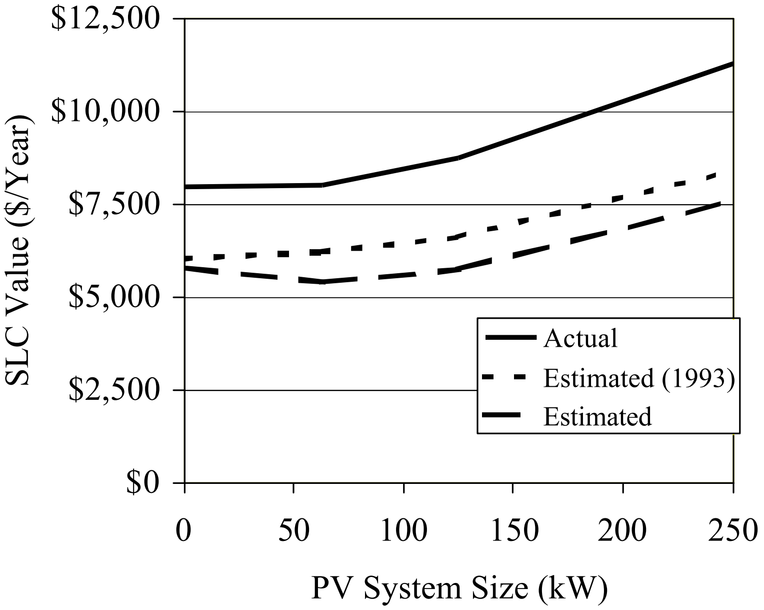


Figure 4. SLC value as a function of PV system size.

Several observations can be drawn from these tables and the associated figure:

- First, the SLC provides between $5,000 and $12,000 in additional demand savings depending upon data source and the PV system size for a building with a 1,200 kW peak annual load.
- Second, while there is no portfolio effect of added value for the SLC for PV sizes under 10 percent of peak demand, there is a portfolio effect at higher PV penetrations.
- Third, the model provides an acceptable estimate of the actual value; although the individual monthly estimates can be off in some months, particularly at higher PV penetrations, it is interesting to note that the models (particularly the TMY-based model) tend to be on the conservative side – one of the reasons for this is the fact the modeled loads are smoother (i.e., broader peaks) than actual loads, hence do require more control to be addressed.
- Fourth, an average TMY year data set provides approximately the same result as a time-correlated TMY data set.

# Uninterruptible Power Supply (UPS)

## Introduction

There has been a growing concern among business owners that the local utility may not be fully equipped to provide a level of reliability that adequately meets their business' needs. As a result, greater attention is being given to guaranteeing reliability through the use of customer-sited solutions. The most popular solution is an uninterruptible power supply (UPS).

A UPS is typically limited to providing power for only a short period of time. This is because the cost of the storage component can become significant if one attempts to provide power for long durations.

This limitation can be overcome by combining the UPS with on-site generation. On-site generation may extend the duration through which the UPS can carry the business through the outage. On-site generation reduces the load so that less energy is required from the UPS to meet the load and it also recharges a depleted UPS if the on-site generation produces power in excess of the amount required to meet the load.

## Methodology

The section describes how the Clean Power Estimator program is modified to provide quantitative, site-specific, results comparing the effectiveness of a UPS system (i.e., number of hours of protection) with and without a customer-sited PV system. PV size, configuration, and UPS size are input variables to the simulations.

The evaluation is performed as follows.

1. Determine the critical load during an outage
2. Subtract PV output from the critical load.
3. Calculate the outage prevention hours provided by the UPS based on storage state of charge for every hour in the year

4. Create summary statistics on the hours of prevention (average and worst case) for each month of the year

### Step 1

The first step in the evaluation is to estimate what the load would be during an outage. This is determined by multiplying the actual load times some fraction between 0 and 1. That is, the load during an outage will be less than or equal to the load during normal operation. The critical load is specified by the user.

### Step 2

The second step is to subtract PV output from the load to determine critical load with PV.

### Step 3

The third step is to assume that an outage occurs at a given date and time and then to calculate the hours of outage prevention provided by the UPS. For example, assume that there is an outage on January 1 at 12:00 am. The building's critical load is120 kWh from 12:00 to 1:00 and 60 kWh from 1:00 to 2:00. Storage capacity is 160 kWh at a discharge rate of 120 kWh/hour and 200 kWh at a discharge rate of 60 kWh/hour.

The calculation for this hour is performed as follows:

- The UPS state of charge at 12:00 (the beginning of the outage) is 100%.
- The UPS state of charge at 1:00 is 25% (1.0 - (60 min/60 min)*(120 kWh/160 kWh) = 0.25).
- The UPS state of charge at 12:50 is 0% (0.25 - (50 min/60 min) * 60/200 = 0).

Thus, the UPS system provides 1 hour and 50 minutes of outage protection.

This calculation is repeated for every hour in the year.

### Step 4

The fourth step is to create summary statistics on the hours of prevention. The statistics include average results and worst case results for each hour of each month of the year.

## *Illustration of Methodology Using Westchester Building Load*

In order to illustrate how this method works, take the Westchester building load on April 5 between 06:00 and 18:00 (see the top portion of Figure 5). For illustration purposes, assume that storage capacity is independent of discharge rate and that it equals 200 kWh. There is a 75 percent round-trip efficiency if PV output exceeds the critical load and can charge storage.

The black line in the top of Figure 5 is the load under normal conditions. The red line is the critical load (it is assumed that the critical load is 33% of the normal load). The solid blue line is the critical load minus the PV output.

The three lines in bottom portion of the figure present the UPS state of charge assuming that an outage occurs at 07:00. The dashed black line is included for reference purposes; it immediately goes to 0 indicating that, without a UPS system or PV system, there is no outage protection. The red line, which corresponds to a UPS only system, indicates a UPS alone will provide 1.5 hours of protection. The blue line, which corresponds to a UPS plus PV system, indicates that a UPS plus PV system will provide 9 hours of outage protection for an outage starting at 07:00.

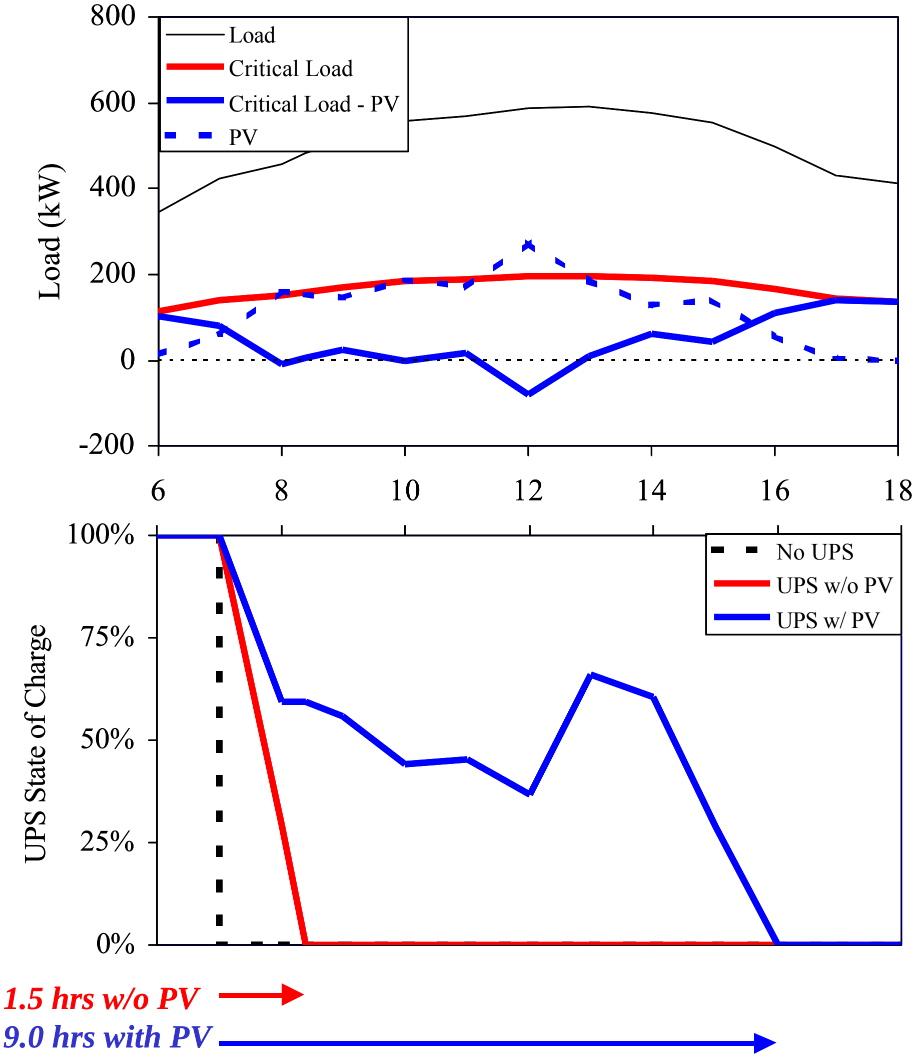
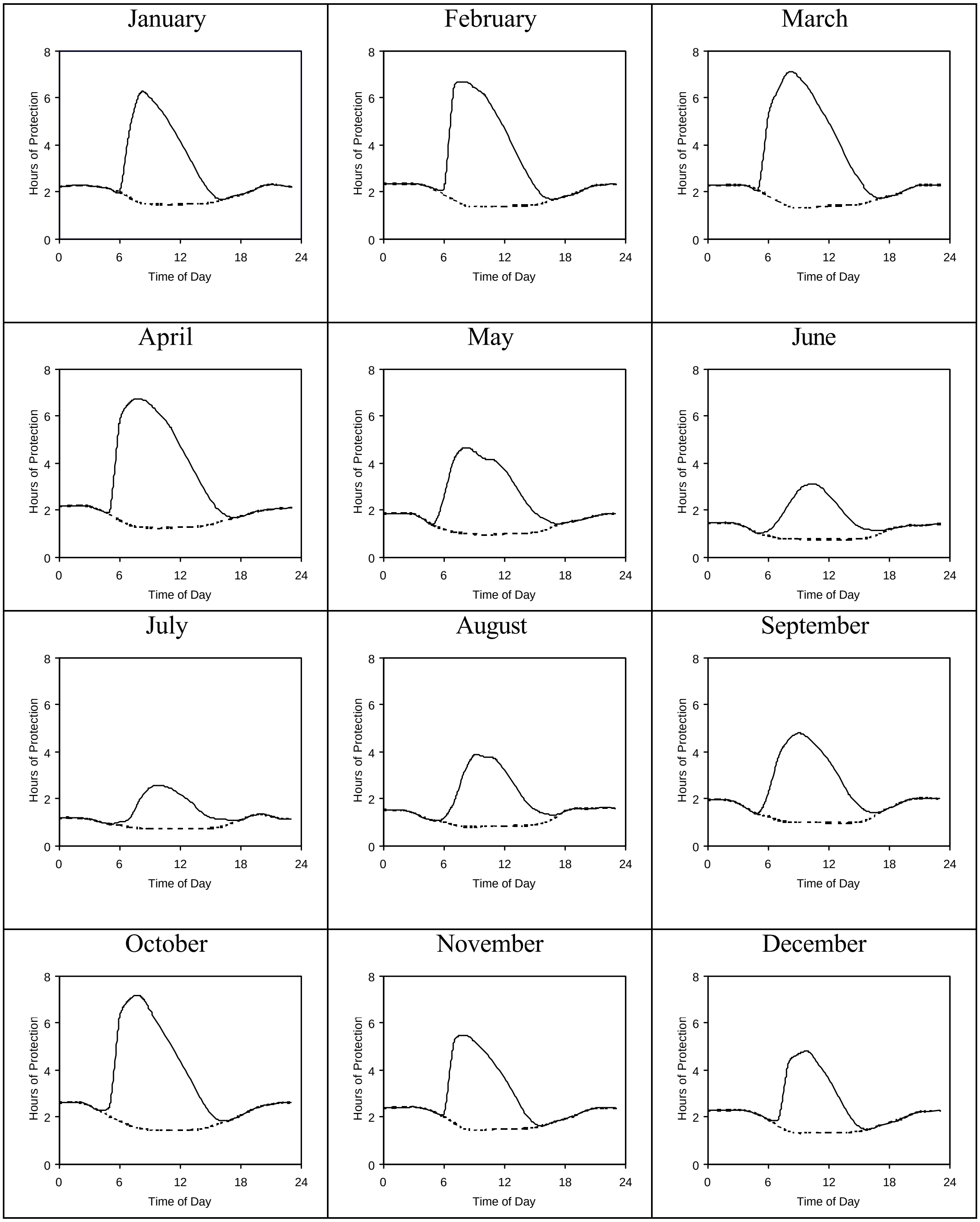


Figure 5. Illustration of protection for a 07:00 outage (data for April 5).

This calculation was repeated for every hour of the year for the Westchester building, with and without the PV system. Summary information was then assembled. The results are presented in Figure 6 (average protection) and Figure 7 (worst case protection). For example, Figure 6 suggests that, on average in January at 9:00, the UPS system alone would provide less than 2 hours of protection for outages while a UPS plus PV system would provide 6 hours of protection.



January

February

March

April

May

June

July

August

September

October

November

December

Figure 6. Average hours of protection with and without 250 kWac PV
(200 kWh of storage, critical load is 33% of normal load)

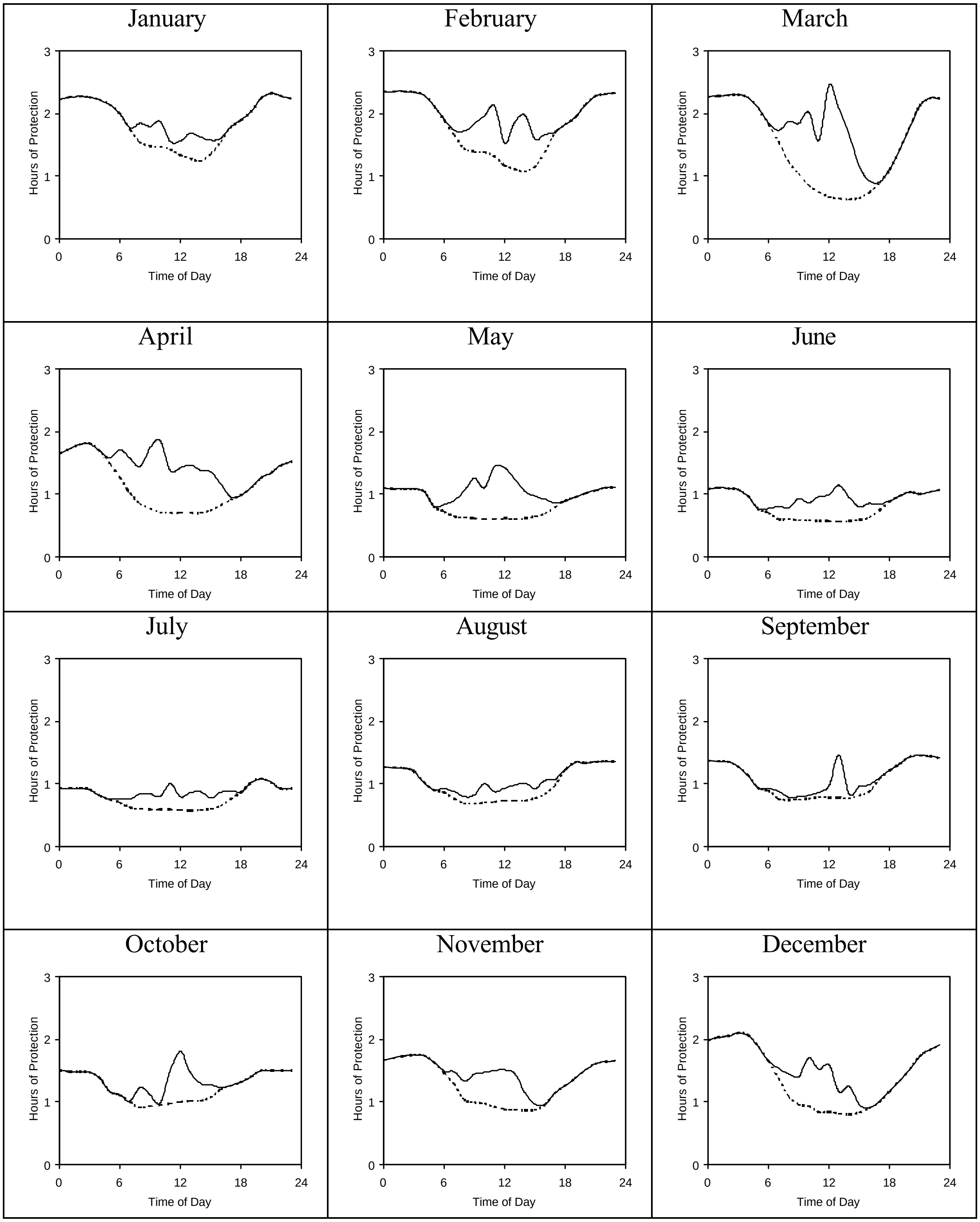


Figure 7. Worst case hours of protection with and without 250 kWac PV
(200 kWh of storage, critical load is 33% of normal load)

## Conclusions

The objective of the paper was to estimate the value of added demand reduction (through use of the SLC) and enhanced UPS efficacy using a minimal amount of data. In particular, the goal was to estimate the value using only sample load profiles and non-correlated PV output data. The algorithms are integrated into a commercial building version of the Clean Power Estimator (CPE) to perform the analysis.

The findings are as follows:

1. The Clean Power Estimator, using only an average load profile, is a good estimate of the actual economic value of the SLC based on the measured hourly Westchester building load and PV output data.
2. There can, however, be noticeable –but conservative -- variation in the individual monthly demand reduction results, particularly as the size of the PV system increases. We plan to investigate this issue further by working on a more refined load simulation model.
3. A UPS plus PV system can protect building owners from much longer daytime outages than a UPS system alone. In a follow-on phase we plan to extract an economic benefit value from the enhanced UPS outage protection results presented above.

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