# DETERMINATION OF THE END-USE EFFECTIVE CAPACITY OF PHOTOVOLTAICS

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**ABSTRACT:** The effective capacity of user-sited, grid-connected PV systems was experimentally determined for several utility customers in the US. These results are analyzed and discussed as a function end-use categories, including office buildings, hospitals, airports and residences. Highest effective capacities were found for office buildings, where PV systems would systematically reduce demand bills by more than 65% of installed PV capacity.
Key Words:

## 1. BACKGROUND

### 1.1 Defining and quantifying effective capacity

The effective capacity of a power plant is its contribution to the generating capacity available, either regionally or locally, to meet electrical load requirements. Photovoltaic power plants have traditionally been given little or no capacity credit. However, several recent studies have shown that PV's effective capacity could be considerable when load drivers are well correlated with the solar resource.

There are many parameters by which effective capacity may be quantified. In this paper, we use two complementary indices: the *Effective Load Carrying Capability (ELCC)* and the *Minimum Buffer Energy Storage (MBES).* The ELCC is a statistical measure of a power plant's effective capacity. It is defined as the effective increase in available capacity at constant loss-of-load probability due to the addition of this power plant. By contrast the MBES is a deterministic measure of effective capacity. The MBES is the minimum amount of stored energy necessary in addition to the considered power plant to insure an effective capacity of 100%. Both indices are a function of the relative size of the power plant with respect to the considered load – i.e., its load *penetration.*

We use relative units for both indices: Percentage of installed -PV- capacity for the ELCC, and installed capacity-hours for the MBES.

Both ELCC and MBES can be determined from statistically significant experimental load and plant generation hourly or higher frequency data (see Perez et al., 1996).

### 1.2 Regional distribution of PV capacity in the US

In previous work the authors have derived the effective capacity of PV for over fifty, mainly north American, utilities by analyzing actual load data and site/time coincident PV output (Perez et al., 1995, 96). The findings of this investigation were counter-intuitive, as high effective capacities were often found in areas with modest solar resource, such as the northeastern US. Indeed, PV effective capacity was not found to be correlated with the local solar energy resource. On the other hand, effective capacity was found to be highly correlated with simple load shape parameters (Fig. 1).

Applying Fig. 1 to load shape data gathered for the majority of US utilities allowed us to map-out the distribution of PV ELCC in the country -- an initial map based on one-year of load data was initially produced (Perez et al., 1995). The map presented in Fig. 2 is based on 8 years of data. It confirms the preliminary trends: effective capacity is highest in regions that experience (a) high summer demand peaks driven by commercial - day time - air conditioning; (b) little electric heat load and (c) pronounced summer heat waves. These regions are: The southwestern US, the central Great Plains, and the northeastern metropolitan area extending from Washington, DC to Boston, MA. *Note that the large Western US power outage of August 10, that was caused by high summer demand fueled by a major heat wave, fully confirmed the high effective capacity potential of PV, (Perez et al., 1997).*

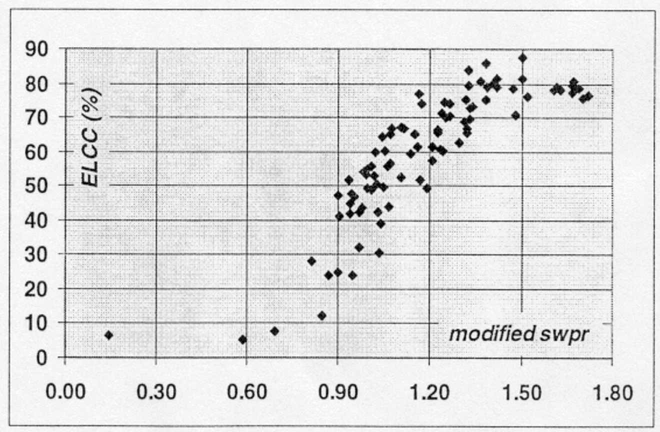


**Figure 1:** Experimentally-derived ELCC for 115 utility load-years as a function of load shape characteristics (modified summer-to-winter-peak-load-ratio, *swpr*)

The map in Fig. 3 shows the US distribution of PV capacity as quantified by the MBES index. It is remarkable to notice that less than one system hour of stored energy would be necessary to increase PV capacity to 100% throughout much of the country.

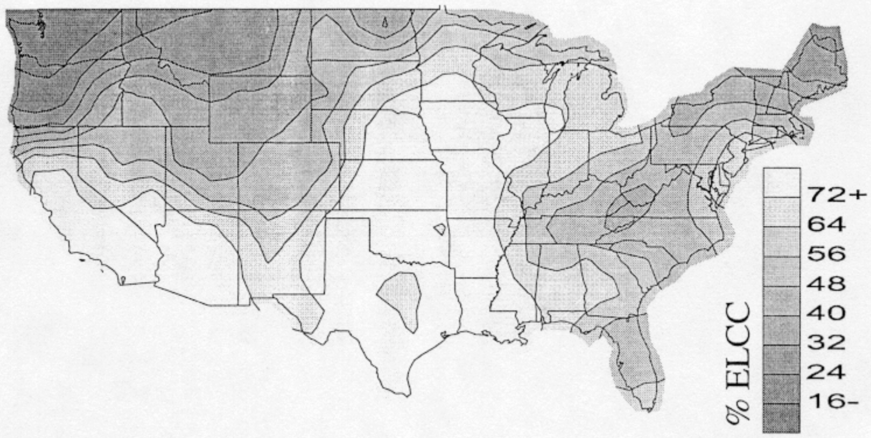


**Figure 2:** Distribution of PV's Effective Load Carrying Capability in the US (2-axis tracking PV at 2% grid penetration)

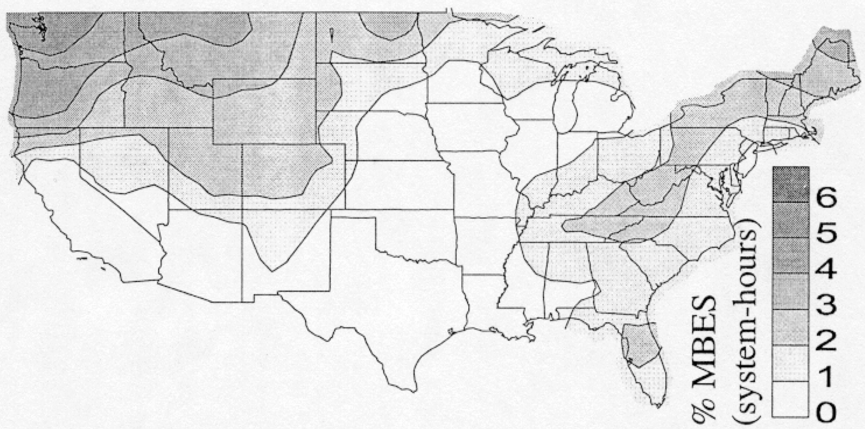


**Figure 3:** Distribution of the Minimum Buffer Energy Storage necessary to increase PV's effective capacity to 100% (2-axis tracking PV at 10% grid penetration)

## 2. END USE PV CAPACITY

### 2. 1 Rationale

End-use or localized effective capacity is an important piece of information for two reasons:

1. **Customer-side economics:** Utility-wide capacity figures discussed above provide a measure of the capacity credit that utilities should give to distributed PV systems. However, the only way a customer-sited PV plant can realize its capacity value today is by reducing end-use demand. This value is directly proportional to the end-use effective capacity of PV.
2. **Transmission and distribution (T&D) benefits:** It has been shown (e.g., Wenger et al., 1997) that much of the value of a distributed PV power plant may reside in its localized grid support capabilities (e.g., upgrade deferment, reduction of wear and tear, outage mitigation, etc.). This grid support capability is directly linked to PV's localized effective capacity, which may or may not match regional capacity -- high value/high capacity conditions may exist in regions with low utility-wide effective capacity such as the northwestern US (Bryan et al., 1996) or, we suspect, much of Europe. T&D effective capacity is closely related to that of the customer mix served by the considered transmission or distribution systems.

### 2.2 Experimental Determination of End-use capacity.

PV effective capacity was experimentally derived for 21 end-use/local loads (Table I). Loads cover several orders of magnitude size-wise and include residences, airports, hospitals, schools and office buildings – all office buildings are air-conditioned and two are electrically heated (heat pumps). Loads are geographically distributed throughout the US, with a predominance on the East Coast.

Most of these sites have operational PV plants where solar radiation is monitored -- plane of array and/or global/direct/diffuse irradiance. For consistency and comparison purposes, PV output was modeled from radiation data for two nominal array types: fixed at latitude minus ten degrees and 2-axis tracking (Perez et al., 1996).

**Table 1:** End-use and localized loads considered in this paper

| Load Name | Load type | load size kW | Service Territory | years studied |
|---|---|---|---|---|
| World trade Center (NY City) | Office | 73,024 | New York Power Authority | 93 |
| JFK Airport (NY City) | Airport | 56,900 | New York Power Authority | 93 |
| Jacob Javits Convention Center (NY City) | Offices/Convention | 14,960 | New York Power Authority | 93 |
| Kerman Substation (Kerman, CA) | Substation | 10,627 | Pacific Gas and Electric | 91,92 |
| La Guardia Airport (NY City) | Airport | 9,320 | New York Power Authority | 93 |
| Woodhull Hospital (NY City) | Hospital | 5,128 | New York Power Authority | 93 |
| Harlem Hospital (NY City) | Hospital | 3,128 | New York Power Authority | 93 |
| Westchester County Building (White Plains, NY) | Office | 1,265 | New York Power Authority | 93 |
| Northeast Utilities Service Ctr. (Berlin, CT) | Office (electric heat) | 877 | Northeast Utilities | 94 |
| Elmhurst Hospital (NY City) | Hospital | 795 | New York Power Authority | 93 |
| NYSEG Service Center (Plattsburgh, NY) | Office (electric heat) | 645 | New York State Electric & Gas | 94 |
| White Plains Middle School (White Plains, NY) | School | 633 | New York Power Authority | 94 |
| Office Building, (Reston, VA) | Office | 495 | Virginia Power | 96 |
| Atlantic Electric Headquarters (Pleasantville, NJ) | Office | 409 | Atlantic Electric | 94 |
| WPS Service Center, (Ashwobegon, WI) | Office | 287 | Wisconsin Public Service | 94 |
| NC Power Headquarters (Roanoke Rapids, NC) | Office | 154 | North Carolina Power | 96 |
| Palm Desert (CA) | Office | 94 | Southern California Edison | 94 |
| Minnetonka (MN) | Office | 38 | Northern State Power | 94 |
| UCS Building Cambridge (Mass) | Office (energy efficient) | 33 | Cambridge Electric | 96 |
| Denmark (WI) | Residence | 15 | Wisconsin Public Service | 94 |
| Edwards Airfoce Base (CA) | Residence | 7 | Southern California Edison | 94 |

## 3. RESULTS

### 3.1 Effective Capacity and Load Shapes

One of the objectives of this investigation was to find out whether the load- PV capacity relation observed at the utility scale (Fig. 1) remained true for local smaller end-use loads (Fig. 4). We note that loads greater than 250 kW (i.e., mid-size office buildings and up) follow the same trend as utility loads.

This result is noteworthy because it signifies that effective capacity for 250 kW-plus loads can be easily gauged from a few load shape parameters (Perez et al., 1996). Smaller loads tend to be noisier and tend to progressively depart from the trend.: this is because small individual loads tend to fluctuate independently from the underlying load drivers that are at the basis of Fig. 1 relationship.

### 3.2 Building-type Tendencies

Our main objective was to attempt to identify PV capacity potential as a function of building type. As of this writing, our experimental load sample is not quite large enough to provide definitive results, however we note emerging evidence of building type trends.

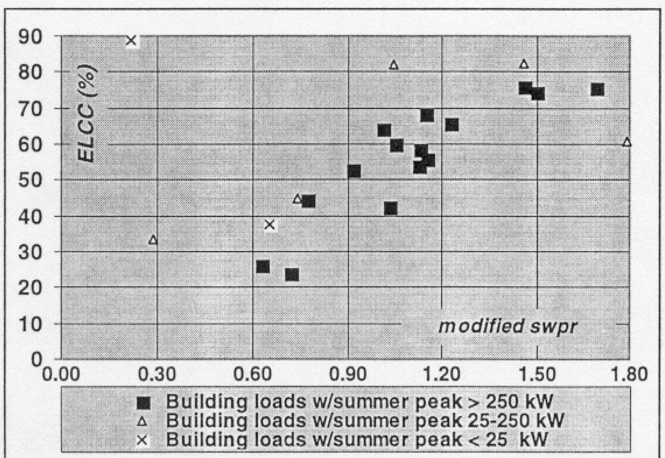


**Figure 4:** Same as Fig.1 but for building loads

In Table II, we report the average and standard deviation of the ELCC and MBES parameters. These parameters were evaluated for 2% and 10% load penetration respectively, and for tracking PV configurations. *For information, the ELCC of fixed, south facing PV systems is typically 10-15% less than for tracking systems. However the ELCC of tilt/azimuth-optimized fixed PV arrays has been found to be within a few percent of the tracking ELCC.*

**Office Buildings:** Highest ELCCs, averaging 66%, are found for air-conditioned office buildings. The MBES parameter shows that less than one hour of storage would be needed, in addition to a PV system, to guarantee a firm 10% demand reduction for this type of building. Noting that office buildings represent our largest load sample and that standard deviations are small, these results may be considered as representative of this building class.

**Office buildings with electric heat:** As would be expected, buildings with a sizable heat-driven electric winter load exhibit a much smaller PV effective capacity, indicating poor instantaneous match between heating requirements and solar availability.

**Hospitals:** Effective capacity, as gauged by the ELCC, stands at 63%, showing a good statistical agreement between the resource and the load for very low penetration levels. The MBES, however, is considerably higher than for office buildings, standing at almost 3 hours. This is indicative of high and lasting shoulder loads for hospitals.

**Airports:** Both capacity parameters indicate only marginal load matching for these mainly 24 hr./day operations.

**Residences:** The high average ELCC is probably an artifact of our low data sample (one of the residences happens to be in a very sunny climate with a narrow peak load at noon). The high standard deviation confirms that this statistic is not very solid. However, it is remarkable that the MBES is small with a very low standard deviation. This is because, as residential loads are typically noisy, it does not take much energy reserve to substantially reduce peak loads.

Only one **school** was available. PV capacity was found to be low for the considered school. This building-type trend cannot be generalized. However, it is important to remark that this building fits remarkably well within the load shape-capacity trend shown in Figs. 1 and 4. It means that the low PV capacity observed for this school was directly predictable from the low air-conditioning usage and low summer activity of this building.

**Table II:** Building type effective capacity tendencies

| | Average ELCC (%) | Standard Deviation (%) | Average MBES (hours) | Standard Deviation (hours) |
|---|---|---|---|---|
| Offices (no electric heat) | 66% | 0.12 | 0.9 | 0.5 |
| Residences | 39% | 0.39 | 0.6 | 0.2 |
| Hospitals | 63% | 0.11 | 2.3 | 1.2 |
| Airports | 33% | 0.13 | 4.3 | 1.2 |
| Offices (electric heat) | 30% | 0.05 | 1.3 | 0.7 |

### 3.2 Economic implications

Several recent articles (e.g., Wenger et al., 1997, Perez et al., 1997) have shown that customer-side PV constitutes an effective option for dispersed grid-connected PV deployment. Customer-side PV systems benefit form attractive customer-side retail electricity economics, while providing dispersed grid support for utilities. *This deployment scope is very large: Commercial buildings alone amount to more than 50 square km of new roof space per year in the US (EIA, 1997), ultimately capable of supporting the deployment of 5 GW of PV per year..*

This paper shows that, in the case of office buildings, the economic interests of utilities and customer PV owners directly coincide because dispersed grid benefits are directly valued at the customer level through retail demand reduction.

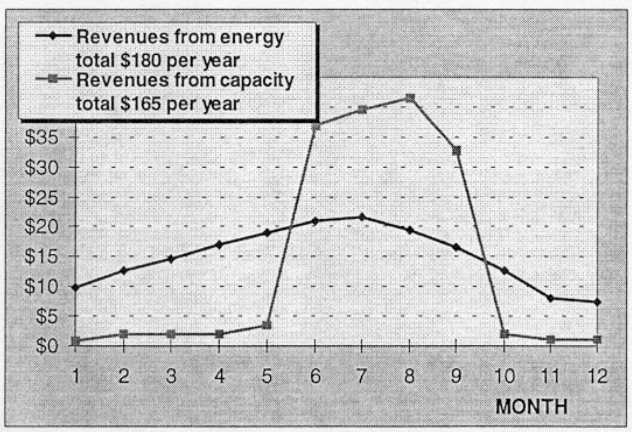


**Figure 5:** Customer-sited PV plant monthly revenues (LilCo, Volontary large demand Metered rate PSC-282)

The case of Long Island Lighting Company (LilCo) provides a powerful example of this coincidence of interest. LilCo is a utility company with high peak time energy/demand rates reflective of localized peak capacity constraints. Its Voluntary Large Demand Metered rate scale bills demand at more than $40/kW from June to September (New York Public Service Commission, 1996). The coincidence between demand value and LilCo's PV monthly effective capacity is shown in Fig. 5. A simple life cycle cost analysis for a commercial customer-owned PV power plant leads to a break-even PV turnkey cost of $5,700/kW-ac. This cost is of the order of current large PV order quotes (e.g., Osborn et al., 1997). When considering the system's energy value only, the break-even cost only reaches $3,200/kW-ac, a figure which is not achievable today without direct or indirect societal support.,

## CONCLUSIONS

The two key results of this paper are:

(1) The relationship between PV effective capacity and load shape characteristics observed at the utility/regional level remains applicable for building loads as small as 250 kW.

(2) Effective capacity for air-conditioned office buildings averages over 65%, that is well in line with PV's capacity for the majority of US utilities. We also showed that a small amount of energy reserve – of the order of one system hour – would increase this effective capacity to 100%.

These results are important in light of the considerable PV deployment potential of new and existing office buildings, because they provide evidence that enhances and legitimizes the value of customer-owned grid-connected PV applications.

## ACKNOWLEDGMENT

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