

Solar-to-Vehicle (S2V) Systems for Powering Commuters of the Future

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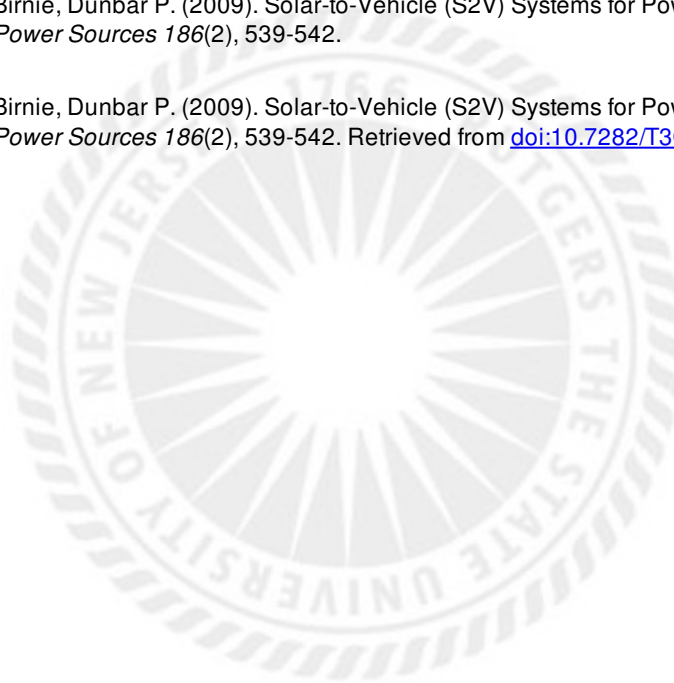
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Citation for this version and the definitive version are shown below.

Citation to Publisher Birnie, Dunbar P. (2009). Solar-to-Vehicle (S2V) Systems for Powering Commuters of the Future.
Version: *Power Sources* 186(2), 539-542.

Citation to *this* Version: Birnie, Dunbar P. (2009). Solar-to-Vehicle (S2V) Systems for Powering Commuters of the Future.
Power Sources 186(2), 539-542. Retrieved from [doi:10.7282/T3QJ7FF0](https://doi.org/10.7282/T3QJ7FF0).



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Solar-to-Vehicle (S2V) Systems for Powering Commuters of the Future

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To appear: *Journal of Power Sources*
(Accepted: 27 September 2008)

ABSTRACT

Hybrid electric vehicles are growing in popularity and significance in our marketplace as gasoline prices continue to rise. Consumers are also increasingly aware of their carbon “footprint” and seek ways of lowering their carbon dioxide output. Plug-in hybrid and electric vehicles appear to be the next wave in helping transition from a gasoline-based transportation infrastructure to an electric-grid sourced mode, though most plug-in scenarios ultimately rely on having the electric utilities convert from fossil sources to renewable generation in the long run. At present, one of the key advantages of plug-in hybrid/electric vehicles is that they can be charged at home, at night, when lower off-peak rates could apply. The present analysis considers a further advancement: the impact of daytime recharging using solar arrays located at commuters’ work sites. This would convert large parking areas into solar recharge stations for commuters. The solar power would large enough to supply many commuters’ needs. The implications for electric car design in relation to commuter range are discussed in detail.

Keywords: Solar power, hybrid electric vehicles, plug-in hybrids, commuter vehicles

INTRODUCTION

Recent discussions of climate change have focused on anthropogenic sources of carbon dioxide and the cumulative effect of these emissions that, over time, are expected to have grave impacts on global environment and society in general [¹]. In fact, recent shifts toward encouraging ethanol production to offset vehicle fuel needs appear to have contributed to shortages of other grain stocks as farmers shift to corn to meet the ethanol production demands [^{2,3}]. One of the key reasons that ethanol has been pushed so extensively is that more than 25% of our aggregate national energy needs are for transportation [⁴] – and these needs depend almost completely on fossil fuel sources (much of this imported from overseas). Clearly, finding ways to support our transportation needs without depending so heavily on foreign oil is critical for our political and economic advancement.

One trend that helps ease these constraints is the increasing popularity of hybrid vehicles, with the Toyota Prius being the most successful model having sold over one

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million worldwide through April of 2008 [5]. Hybrids have two key advantages in their design that help them achieve substantially higher fuel economy: First, since electric motors and internal combustion engines have ideal efficiency at low and high speeds respectively, then they can share the power load and reach an overall higher system energy efficiency. Also, electric motors provide a second functionality – they allow for “regenerative braking” that then recoups some of the car’s motional energy and recharges the battery a bit every time you hit the brakes instead of the normal frictional losses.

As soon as hybrid vehicles became available then hobbyists and electric vehicle enthusiasts were quick to design custom conversions that would allow them to plug-in to grid sources for power [6-11]. And, now mass production plug-in commercial versions are in development and expected to reach the market soon [12-15]. Then during short range driving only electric power can be used – allowing for the beneficial economy of electric motors that incorporate regenerative braking and the lower prices for grid-sourced electricity.

Willett Kempton and others have seized on the plug-in hybrid/electric concept and pointed out an additional advantage: that the batteries in these vehicles can store cheaper nighttime power and deliver it back to the grid during daytime hours when demand for electricity is highest [16-18]. Their notion of “vehicle-to-grid (V2G)” connections is appealing but provides only partial abatement of our dependence on fossil fuel since only a fraction of our grid electric generation is from renewable sources. For example, Stephan and Sullivan have examined PHEV use and determined that the CO₂ emission reduction would be around 25% in the short term [19,20]. To the extent that wind or solar can be used to charge the PHEV’s then we could achieve the full 100% reduction of CO₂ emissions even compared to the excellent gas mileage that is achieved by hybrid vehicles already. However, if we limit ourselves to night-time charging at home then solar power is out of the question, though wind generation is clearly viable [17]. On the other hand, the present work advocates situating solar generation capacity where daytime charging of PHEV’s would be especially convenient: in large parking lots where commuters typically leave their vehicles all day long. This concept is developed and analyzed in the next section.

CONCEPT

Solar arrays installed as shade structures over parking lots used by daily commuters could provide daytime charging of their electric vehicle batteries and reduce our dependence on fossil fuel for transportation and simultaneously help to level generation/demand imbalances that are intrinsic with direct solar-to-grid generation. When evaluating this concept it is useful to compare the energy generating capacity, timing, storage capacity and other practical aspects related to electric, hybrid electric, and plug-in hybrid vehicles that might be used in such systems.

The practicality of such “Solar-to-Vehicle” (S2V) systems will depend on two overlapping factors: (1) the regional solar energy influx and its seasonal variation, and (2) the population density and typical commuter transit distances. For regions where weather patterns or latitude reduce the solar energy influx then it may be difficult to collect enough energy during working hours to satisfy the round-trip energy needs of the commuter. Similarly, depending on the round-trip commuting distance, traffic congestion, and other factors, the energy demand may just be too high. Both factors are

examined here, which helps us develop recommendations about PHEV specifications that will optimize this commuter mode.

The National Renewable Energy Laboratory (NREL) has provided data that are useful for analyzing solar collectors in various configurations and locations around the country. Of particular use in the present case is the “Typical Meteorological Year (TMY)” database [21]. Datasets are available for numerous locations around the United States. For general midlevel comparisons it is fair to work with our local New Jersey data and recognize that some areas of the US will be better and some worse. Figure 1 shows lines for three selected, reasonably sunny days of energy flux incident on a horizontal plane (as a function of time throughout each day). This highlights the seasonal variations; *average* brightness values are about 30% lower, though, when weather variations are considered. The key point from this graph is that, as expected most of the light available for solar capture actually occurs within the peak working hours of 9AM to 5PM! The graph also illustrates the increasing number of daylight hours in the summer time for the Newark, NJ latitude (40° 41' 45"). Figure 2 shows a plot of the full seasonal variation including the effects of weather. For our estimation purposes, it is reasonable to use average data that show the practical seasonal variation in available sunlight that could be expected. This average line is superimposed.

At this point it is useful to work with these data to estimate what the practical solar collection amounts might be for parking shade structures that could be installed as workplace parking lot collector arrays. Two additional factors are required: the expected efficiency of solar panels and the nominal area for a typical parking space size. Surveying several manufacturers offering larger power modules (in the 200Wp range) we find expected efficiency values to be in the range of 13-14% [22]. Similarly, parking space geometries are relatively standard with widths of 8 to 10 feet being typical and lengths being in the 18 to 20 foot range. Converting to metric then we might expect an average parking space to occupy approximately 15 square meters of area. If this entire area were used for a horizontally situated solar collector then our average daily summertime solar generating capacity would be around 12,600 Whr ($\sim 6000 \text{ Whr/m}^2 * 0.14 * 15 \text{ m}^2$), while in the wintertime the average daily generating capacity would be around 3,780 Whr ($\sim 1800 \text{ Whr/m}^2 * 0.14 * 15 \text{ m}^2$).

These solar generating capacities are interesting when viewed in comparison to the battery pack used in a normal Toyota Prius hybrid. The most recent model is outfitted with a battery pack that is capable of storing 1300 Whr. So, even in the wintertime there is substantially more solar energy available than what the system can store; modification of the system should be envisioned to achieve a longer range and fuller utilization of the available solar power. Even though user modification of the system isn't sanctioned by any warranty from Toyota, there is still quite a bit of information available on the internet that demonstrates Prius conversions to create plug-in hybrids (PHEV's), as noted above [6-11] or a modification that allows the Prius to run in the fully EV mode albeit only at city traffic speeds [23]. Without extending the battery capacity then the Prius is reported to have a range that might be only a couple miles in electric-only mode. One modification that adds 5000 Whrs of battery capacity is reputed to more than double the Prius's gas efficiency and would extend its electric range to 30-40 miles [8]. Even with this extra battery capacity, the average summertime solar power that is available is substantially above what can be stored; this results in solar power that can be delivered to the grid or

used at the worksite. But, in the winter it is possible that the solar energy that is captured may not be enough to fully power a commuter's energy consumption needs, especially for workers who commute farther.

While the full details of system energy efficiency and achievable EV-only travel range remain to be concretely established, it appears that commuters who live within a 15-20 mile radius of their worksite might be able to become fully solar powered if solar-array parking shade structures were installed at commuter destinations. In fact, US Department of Transportation data show that more than two thirds of commuters travel 15 or fewer miles to reach work and half of the commuters travel 10 or fewer miles one way [24]. Thus with suitable ancillary power storage then daytime charging based on solar collectors of similar size to the car's parking space could achieve fully zero-carbon-load commuting for most people.

DISCUSSION

The analysis given above has shown that solar collectors of a size similar to one's parking space could generate enough power to carry a commuter to and from work using PHEV's with appropriate battery capacity – at least for commuters within a reasonable distance from the workplace. Such a scenario upends the normal cost/benefit analysis that a home owner might invoke when deciding whether to install solar panels on their house. In the normal case the cost of the solar collection capacity is moderated by a reduction in the electric demand that a home owner would experience. Electricity costs then contribute slowly to pay back the initial cost of installation. Depending on the latitude and prevailing weather conditions then this “pay-back-period” could be many years. Most regions have only encouraged moderate private installations though rebate and tax incentive programs for grid-connected home solar collectors [25]. Now if we consider that a solar collector could be integrated into a parking-lot shade structure and immediately allow for substantial gasoline savings then a much more rapid pay-back-period could be imagined; this could encourage a more widespread installation of solar capacity. And, the connection to a large automobile-based commuter population would allow for substantial reduction in green-house gas emissions.

It should also be noted that large workplace parking lots are often relatively open territory where little shade currently exists; solar collectors could be installed without requiring the removal of numerous trees or other obstructions. On the other hand, many home owners find that either their roof is pointing the wrong direction or that nearby trees shade those areas too much for practical implementation (and the trees are often esthetically pleasing in their own right).

Employers could also see an added value to having these shade-structure charging-stations for their commuting workforce. Recent gasoline price rises have already caused definite modifications to workers commuting habits (shifting noticeably toward greater public transportation use) [26]. However, most workers have simply had to bear the brunt of higher commuting costs. Depending on the accessibility of the workplace to public transportation then it may be a difficulty to attract and retain employees; so an employer might view such a solar collector parking structure as part of a multifaceted benefits package, like having on-site daycare or fitness equipment. And, as noted above it is likely that some (or most) of the summertime solar generation capacity will be fed back to the grid or used locally at the workplace anyway, so this immediately

offsets some of the installation costs (though with a longer payback period than a stand-alone solar array might have).

The local power utility might also benefit from such an installation strategy. Having greater daytime solar generation may forestall the need for them to add other generating capacity to keep up with growing demand. Also, many regions are developing regulations that *require* greater amounts of renewable generation [²⁷]. Certainly, society benefits by reducing our output of carbon dioxide as the gasoline requirements for commuter traffic would be reduced.

CONCLUSIONS

A coordinated effort to support the development and advancement of electric vehicles for commuter usage is described. Plug-in electric and hybrid vehicles are best suited to daytime charging with solar collectors that are situated at workplace parking lots. The practical aspects of these systems were described in detail and the overall advantages were outlined. Future widespread electric vehicle use by commuters will depend on having battery pack capacities that are larger than now found in hybrid vehicles. And, workplace solar plug-in parking structures also need to be tested and fielded.

ACKNOWLEDGEMENTS

Support from the McLaren Endowment is greatly appreciated.

FIGURE CAPTIONS

Figure 1: Hourly integrated sunlight brightness for three selected model days from the most recent Newark Airport Typical Meteorological Year database from NREL.

Figure 2: Full year plot of daily integrated sunlight brightness from the most recent Newark Airport “Typical Meteorological Year” database. Scatter is a result of natural cloud and weather variations.

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22. Standard measuring conditions for product comparisons are made at 1000 W/m² simulated solar illumination brightness. The peak output power is then divided by the illumination brightness times the module’s area to arrive at efficiency values. Four manufacturers were compared for similar silicon single or polycrystalline cell modules. No endorsement is implied. Their data sheets can be found here:
http://www.kyocerasolar.com/pdf/specsheets/kd_210gxp_020108_web.pdf,
http://www.gepower.com/prod_serv/products/solar/en/downloads/gepvp200_datasheet_600.pdf,
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23. One EV-only button accessory:
http://www.coastaletech.com/electric_only_mode.htm
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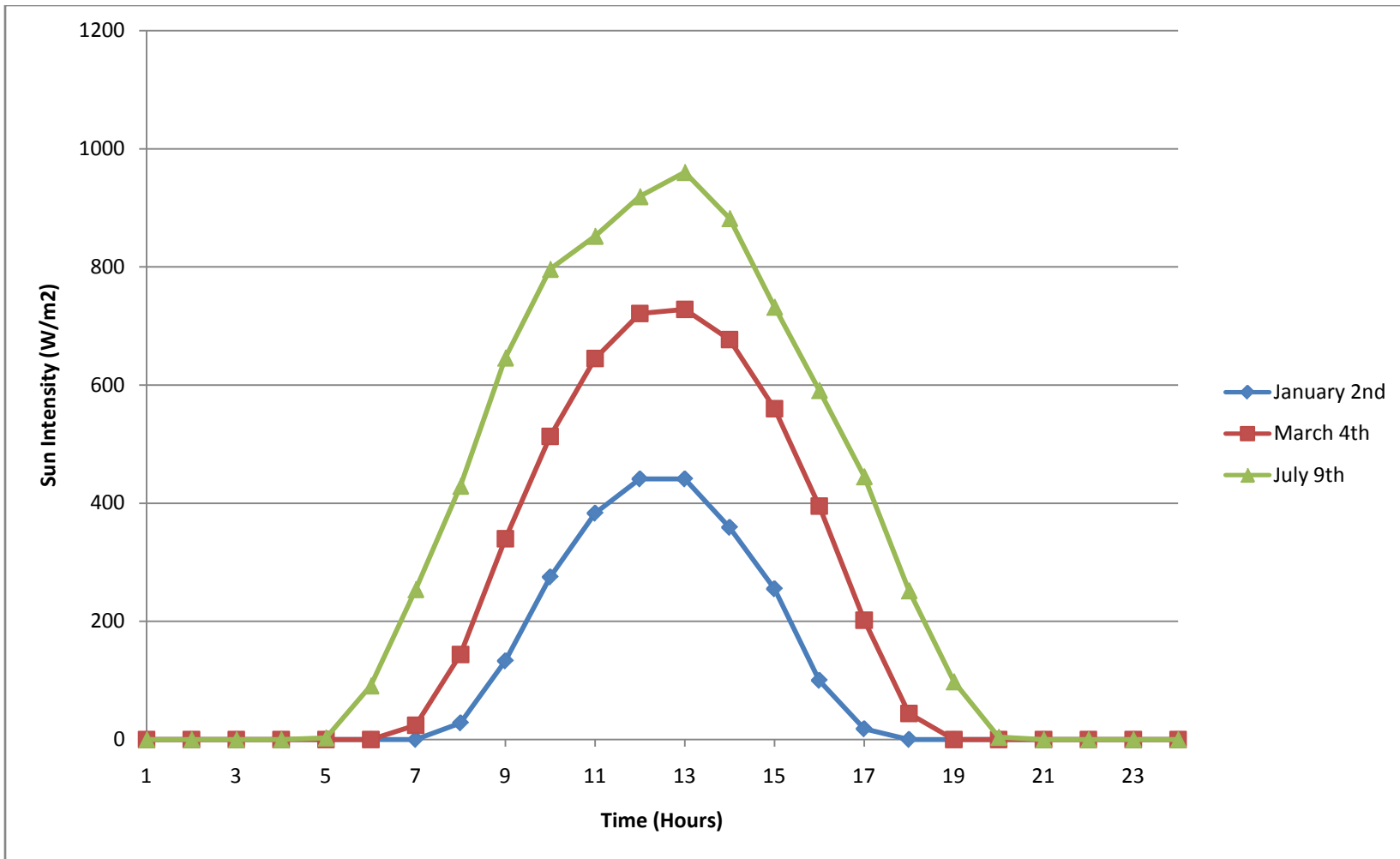


Figure 1: Hourly integrated sunlight brightness for three selected model days from the most recent Newark Airport Typical Meteorological Year (TMY) database from NREL. Data are for all angle illumination onto a horizontal plane having one square meter area.

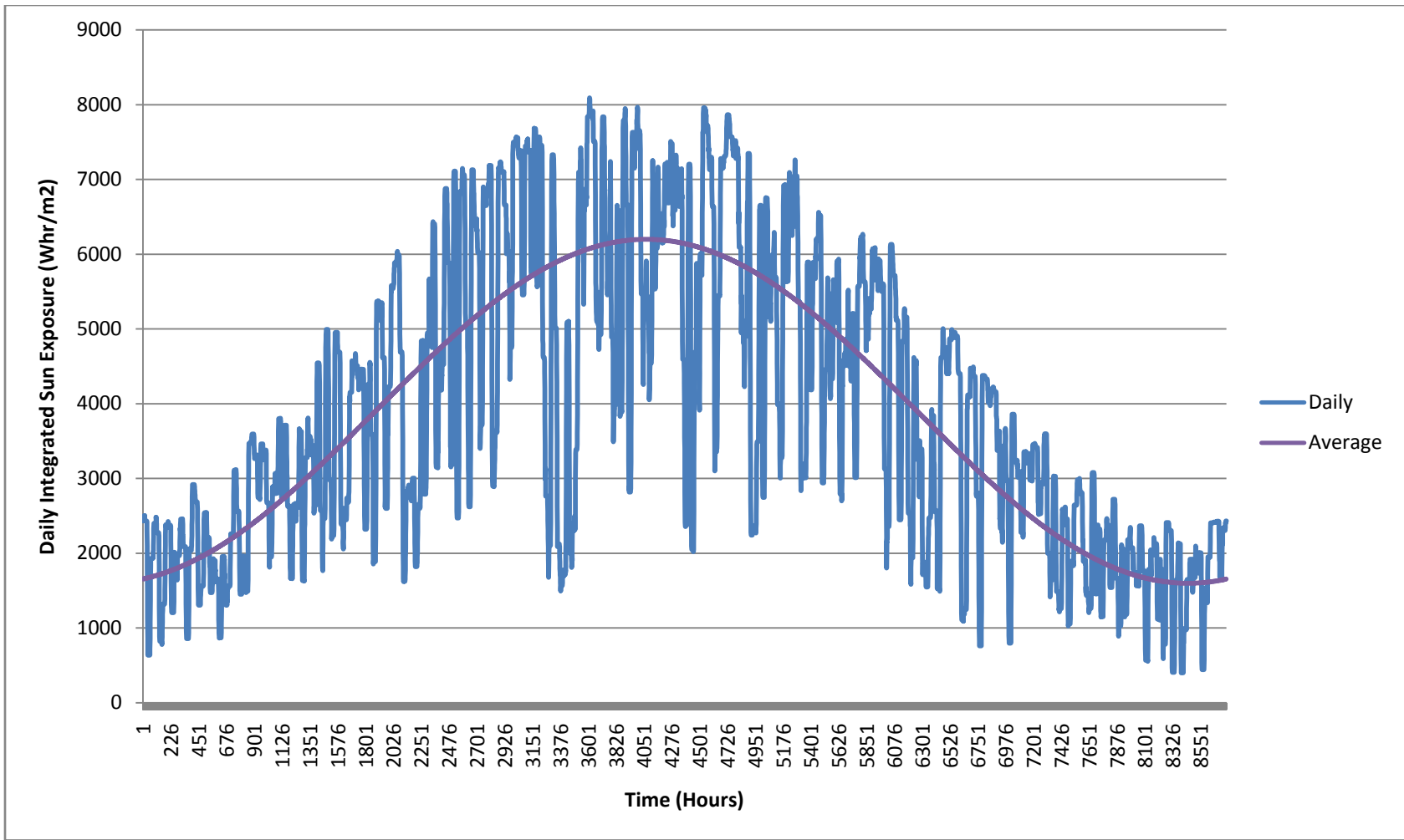


Figure 2: Full year plot of daily integrated sunlight brightness from the most recent Newark Airport “Typical Meteorological Year” database. Scatter is a result of natural cloud and weather variations.