California Solar Initiative

RD&D: Research, Development, Demonstration and Deployment Program

Final Project Report:

West Village Energy Initiative

APPENDIX C:

Task 2-Integration of AMI with Solar PV & other DER Technologies

Grantee:

University of California, Davis

Energy Institute

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Preface

The goal of the California Solar Initiative (CSI) Research, Development, Demonstration, and Deployment (RD&D) Program is to foster a sustainable and self-supporting customer-sited solar market. To achieve this, the California Legislature authorized the California Public Utilities Commission (CPUC) to allocate **$50 million** of the CSI budget to an RD&D program. Strategically, the RD&D program seeks to leverage cost-sharing funds from other state, federal and private research entities, and targets activities across these four stages:

- Grid integration, storage, and metering: 50-65%
- Production technologies: 10-25%
- Business development and deployment: 10-20%
- Integration of energy efficiency, demand response, and storage with photovoltaics (PV)

There are seven key principles that guide the CSI RD&D Program:

1. **Improve the economics of solar technologies** by reducing technology costs and increasing system performance;
2. **Focus on issues that directly benefit California**, and that may not be funded by others;
3. **Fill knowledge gaps** to enable successful, wide-scale deployment of solar distributed generation technologies;
4. **Overcome significant barriers** to technology adoption;
5. **Take advantage of California's wealth of data** from past, current, and future installations to fulfill the above;
6. **Provide bridge funding** to help promising solar technologies transition from a pre-commercial state to full commercial viability; and
7. **Support efforts to address the integration of distributed solar power into the grid** in order to maximize its value to California ratepayers.

For more information about the CSI RD&D Program, please visit the program web site at www.calsolarresearch.ca.gov.

Foreword

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Acronyms and Nomenclatures

AMI	Advanced Metering Infrastructure
CO2	Carbon Dioxide
CPP	Critical Peak Pricing
CSI	California Solar Initiative
DER	Distributed Energy Resources
DR	Demand Response
DSM	Demand Side Management
EEC	Energy Efficiency Center
EMS	Energy Management System
EV	Electric Vehicle
GE	General Electric International, Inc., and GE Energy Consulting
HAN	Home Area Network
HEM	Home Energy Management
IP	Internet Protocol
ITS	Institute of Transportation Studies
kW	Kilowatt
kWh	Kilowatt hours
MEM	Master Energy Manager
MW	Megawatt
MWh	Megawatt hours
NEM	Net Energy Metering
NREL	National Renewable Energy Laboratory
PCT	Programmable Communicating Thermostats
PG&E	Pacific Gas & Electric
PV	Photovoltaic
PVW	NREL PVWatts™ Calculator
SEP 2.0	Smart Energy Profile 2.0

SF	Square Foot
TOU	Time of Use
VNEM	Virtual Net Energy Metering
WCEC	Western Cooling Efficiency Center
WV	UC Davis West Village
WVCP	West Village Community Partnership
ZNE	Zero Net Energy

Executive Summary

California is a global leader in the research, development, and demonstration of new energy technologies, including solar Photovoltaic (PV), energy efficiency, energy storage, and electric vehicles (EVs). UC Davis West Village, as the first Zero Net Energy master-planned community in the U.S., represents a unique intersection of these trends and a blueprint for future development in the State. Under research funded by the California Solar Initiative (CSI) RD&D grant program, UC Davis West Village is also a "living laboratory" for proving out state-of-the-art community-level design and energy management best practices, with the aim of supporting the State's goals of sustainable, low carbon, Zero Net Energy (ZNE) performance for all new construction residential housing.[1]

Beginning in August 2012, GE Energy Consulting (GE) was engaged by UC Davis, as subcontractor under Target Area 1, Task 2 of its CSI grant, to examine the integration of demand side monitoring and control ("AMI") with solar PV and other Distributed Energy Resources (DER) at UC Davis West Village. This report presents the results of our Study, including a baseline model of both consumption and solar PV production for each of the existing and to-be-built building types at UC Davis West Village, as well as recommendations for future energy performance monitoring and control.

Our current model representation of UC Davis West Village's overall performance is as follows:

- Annual Solar PV Electricity Production: 9,271 MWh
- Annual Electricity Consumption: 12,042MWh

While outside the scope of our Study, UC Davis plans to construct a Renewable Energy Anaerobic Digester that will generate approximately 4 million kWh per year of renewable energy. A portion of this electricity will contribute to the UC Davis West Village ZNE goal.

Due to the limitations of the data available at the time of our Study and the challenges encountered in preparation of the baseline energy model, we are not able to make a definitive statement about the current state of overall energy performance at UC Davis West Village based on our model results. However, several directional observations are possible. We believe, based on the information available and the conservative nature of our modeling, that it is likely that:

- The multi-tenant units are performing slightly above Zero Net Energy, with some variation by unit type. The Viridian units appear to have the best performance (C/P

[1] http://www.energy.ca.gov/energy_action_plan/

close to 1), while the Ramble and Solstice units are farther "above ZNE" and may require some additional "tightening" of performance to achieve energy balance.

- The Rec and Lease center and swimming pool area (the "Club" and "Gas" accounts), as well as the Mixed Use commercial spaces appear to have a greater excess of consumption over production, that is, they are farther from achieving the ZNE objective.
- Our model confirms that the planned Faculty Staff housing does appear to be well designed to achieve ZNE performance, with small variations by floor plan and solar array size. However, the studio annex units, which are an optional addition for some home owners, may have difficulty achieving ZNE, due to a lack of roof space to support solar installation.
- Finally, above and beyond the data limitations in our study, there remains uncertainty in the evolution of future loads which have not been estimated adequately, notably the EV charging and energy-intensive operations associated with the Western Cooling Efficiency Center.

In Subtask 2, we developed the functional specification for future control features that could be added to UC Davis West Village to monitor and tighten energy performance over time, as may be needed to maintain the ZNE goal. Our technology recommendations focus exclusively on energy management and demand control systems. We believe these technologies represent the likeliest "low hanging fruit" of investment that can be made within the existing design to most easily modify energy performance at the lowest cost. It is our contention that energy monitoring and control is the missing piece of the puzzle at UC Davis West Village that can help translate *good design* into *good practice*, by translating the concept of ZNE into daily performance tracking and commands that can be issued to compel specific control actions.

The core recommendation is the development of a desktop Master Energy Manager (MEM) to automate the on-going tracking of performance data (ideally hourly interval production and consumption). The MEM would serve as an on-going "living" version of our baseline model and would manage communications both to residents and directly to addressable devices such as programmable communicating thermostats within UC Davis West Village.

For the multi-tenant buildings, we developed cost-benefit examples for three different levels of demand side control program: Consumption Information Only, a static Time-of-Use (TOU) rate with programmable communicating thermostats, and a Critical Peak Pricing (CPP) rate with programmable communicating thermostats. In all three cases, the investment appears to be quite economic, with simple payback periods of less than one year, 1.3 years, and 2.5 years respectively.

1 Introduction

1.1 UC Davis West Village Community

UC Davis West Village is a new construction, master-planned residential community on University-owned land immediately adjacent to the central campus in Davis, California. When complete, UC Davis West Village will provide housing for over 3000 students, faculty, and staff through a mixture of 663 multi-tenant rental apartment units and 343 Faculty Staff housing, as well as commercial and recreational space, transportation, landscaping, and other amenities. The Community was built by the West Village Community Partnership (WVCP) as the Master Developer. WVCP also serves as the property manager for the rental properties and maintains many common areas within the Community.

UC Davis and WVCP collectively have formed the West Village Energy Initiative with an explicit goal of demonstrating leading sustainable design practice through the implementation of a "Zero Net Energy" (ZNE) master plan – meaning that on net, UC Davis West Village is designed to generate enough energy from local, on-site renewable resources over the course of a year to meet the annual electricity consumption of all the residents within the community. Currently, almost every structure within UC Davis West Village is being built with rooftop solar PV and a high level of energy efficient design (in excess of California's stringent Title 24 building code). There are also future plans to add a biodigester as an additional renewable generation source.

Within the multi-tenant structures at UC Davis West Village, there are three different building types, each with a slightly different mix of 2, 3, and 4 bedroom units with different floor plans. By early 2012, the "Viridian" and "Ramble" (Phase 1) buildings were fully constructed, with occupancy increasing throughout the summer and near-full occupancy by the beginning of the fall academic year. For these two building types, a distinct solar PV array has been dedicated to each unit from the rooftop, and is connected electrically via an individual string inverter to the unit's PG&E billing meter for purposes of qualifying for PG&E's solar Net Energy Metering (NEM) tariff (see Figures 1 and 2)[2]. WVCP owns the solar PV. SunPower is the manufacturer and installer for all the existing solar PV at UC Davis West Village and provides on-going monitoring and maintenance via a multi-year services contract.

[2] Tenants do not directly pay their utility bill, as WVCP serves as the customer of record. WVCP pays PG&E and then assesses a monthly fee for utility costs in each tenant's rent.

Figure 1: Bank of PG&E Net Meters

Figure 2: Bank of Individual String Inverters

A third building type, the "Solstice" (previously known as the "Boulevard" apartments) was still under construction at the time of this Study. In addition, the Ramble Phase 2 building was still under construction. These newer buildings will qualify under the new Virtual Net Energy Metering rules adopted by the CPUC in late 2011[3]. Under these rules, apartment units will not require their own individual PV array and inverter. Instead, a virtual allocation of the entire solar array will be allowed, in which the benefit of the aggregate solar output will be divided between the units within the building on a percentage allocation basis.

[3] CPUC Decision 11-07-031. Further information about VNEM can be found at http://www.cpuc.ca.gov/PUC/energy/DistGen/vnm.htm.

SunPower is also the solar contractor for these facilities, except for a small demonstration solar thermal facility at the Solstice[4].

Construction of the Faculty Staff housing at UC Davis West Village has not yet begun, but is anticipated in a pending phase of development. The Faculty Staff housing will be built and sold to eligible UC Davis faculty and staff as ownership properties, with a 99-year ground lease to the land. Unlike tenants in the rental units, who pay an indirect allocation of utility costs in their rent, the home owner will be the PG&E account holder and bill-payer of record. This difference is important in that it is expected to provide more direct incentives for incorporating advanced energy management features, such as "smart", demand responsive appliances and thermostats, within the Faculty Staff housing (see discussion of Program Recommendations in Section 3.5 below).

There are four different floor plan options that will be offered to prospective residents with differences in layout and square footage. Based on the recommendation of the UC Davis team, we have assumed an equal uptake of each design in our model. In addition, up to 206 homes are permitted for an optional studio unit, which the home owner may build and either occupy or lease out as a rental unit. We have modeled these studio units as an additional housing type.

In addition to housing, there are six Mixed Use (MU) commercial spaces on the ground floor of the Viridian complex, which are designated for a combination of light retail (e.g., a grocery/convenience store) and office use. As of the beginning of this study, the MU space was not yet occupied, though several office tenants have since moved in. UC Davis has leased several of the MU spaces for campus staff, including the new offices of the Institute of Transportation Studies (ITS), the Energy Efficiency Center (EEC), the Energy Institute, and the Western Cooling Efficiency Center (WCEC)[5].

While there were no load data available yet for the occupied offices at the time of this Study, a preliminary estimate of energy usage for the MU spaces was created in July 11, 2012 by the Davis Energy Group[6], a consulting firm, and we have relied on their work to populate our model for MU consumption. In addition to portions of the rooftop, solar PV is assigned to the MU buildings from arrays on solar carports in the adjacent parking area. An EV charging

[4] At the time of our Study, UC Davis was investigating solar products from a different manufacturer (funded through the CSI Grant, Target Area 1, Task 1) that would include passive solar hot water, as well as PV generation. We have not attempted to model these "hybrid" (electric/thermal) solar facilities in our study.

[5] Notably, the WCEC will house testing of some energy-intensive building cooling systems, such as commercial chillers, though their precise operating schedules is not known at this time.

[6] "Mixed Use Commercial Space Energy Estimate", Memo to UC Davis West Village Community Design Team, Davis Energy Group, July 11, 2012.

station will be powered by the vertical Sundial tower structure, which is a feature of the Viridian complex (see Figure 3).

Figure 3: UC Davis West Village Sundial Tower

Several months of historical solar production data were available for the MU buildings and are used in our Study.

In addition to housing and the MU space, the Ramble complex contains a Recreation and Leasing office, with meeting/study space, offices, gym facilities, a movie theater, and an outdoor heated swimming pool. While the pool is heated with natural gas, there is electric load associated with the pool pumps required to circulate water and maintain both temperature and chemical levels. The "Rec and Lease" building (also referred to as "Rec Center" or "Club House") was open and fully occupied during the time of our Study, however, due to some delays in calibration of measurement equipment, only partial data history was available for solar production.

Finally, the Community contains several types of miscellaneous common areas with both interior and exterior loads that we have attempted to capture. Each apartment building has lighted open-air hallways, breezeways, and stairways, as well as external lighted pathways and landscaped outdoor areas with irrigation sprinklers. Electric demand associated with these common areas is assigned to a set of separately metered accounts for each building, for which solar facilities are also dedicated (under NEM).

There are plans for plug-in electric vehicle (EV) charging, both for the ITS fleet and in other locations throughout the community, as consumer demand materializes. Insufficient data were available to model EV uptake and charge patterns and this future load was therefore deemed out of scope for the current Study. However, we have provided a placeholder for it in our model.

Finally, the community includes the Davis Center for Sacramento Community College, located on a corner of the UC Davis West Village plot, which is not under direct UC Davis control and has not been included in the ZNE design. We have excluded this building, along with any future out-of-plan facilities that may be located within the community footprint.

1.2 Study Objective

UC Davis is the awardee of a multi-project research grant under funding from the California Solar Initiative (CSI) RD&D program[7]. Overall, the UC Davis West Village CSI grant seeks to examine different aspects of solar usage at UC Davis West Village and demonstrate a range of technologies that will be of value to the state of California and the solar industry in general, as communities throughout the State seek to include solar generation in their strategies to achieve Zero Net Energy, sustainability, and low carbon objectives.

Beginning in August, 2012, GE Energy Consulting was engaged as the subcontractor to UC Davis for Target Area 1, Task 2 of the UC Davis West Village CSI grant, entitled "Integration of Advanced Metering Infrastructure (AMI) with Solar and other Distributed Energy Resources (DER)". The purpose of this Task is to first establish a baseline representation of current energy performance from the available data and designs for UC Davis West Village (Subtask 1), and then to recommend a monitoring and control systems architecture that integrates the customer demand side ("AMI")[8] with solar PV production and other DER technologies, to be able to measure and adjust performance to meet the ZNE goal on a dynamic, on-going basis (Subtask 2).

Achieving the ZNE objective has been a guiding principle in the design of the facilities at UC Davis West Village. While useful as a community-level design construct, ZNE is in fact a difficult quantity to measure on a day-to-day basis, within an evolving community, given all the variations in construction, tenancy, occupancy, and ownership, as well as the limitations in the available data.

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[7] CSI research is funded by the ratepayers of the three major California Investor Owned Utilities under the auspices of the California Public Utility Commission (CPUC). The independent administrator selected by the CPUC to oversee the CSI RD&D program is Itron, which contributed to the review of this report.

[8] We have adopted the loose definition of AMI from the grant, which we understand to include not only data from the meters themselves, but intelligent end-use devices on the customer side of the meter.

In short, GE sought to answer two key questions: How is energy performance tracking compared to the goal of ZNE? And, secondly, where we are not meeting ZNE, what levers are at our disposal to track and adjust energy performance going forward?

Our goal in structuring the Task was to provide UC Davis and the West Village Energy Initiative with the tools to answer these two questions and ensure that ZNE would live on as an operating principle beyond the design phase. By laying out a framework for measurement of ZNE along with recommendations for investment in on-going energy management, we hope to enable the facility managers and UC Davis staff at UC Davis West Village to track and adjust building performance dynamically, for example tightening energy management through automated controls and messaging to tenants, to ensure cost-effective attainment of ZNE.

1.3 Limitations of the Study

A distinct challenge of our work at this early stage in the evolution of UC Davis West Village is that no single "snapshot" of annual energy performance across the community currently exists. New buildings are coming on line and energy system start-up fine-tuning is occurring. For each of the existing, occupied housing unit types and common areas, data on both consumption and solar production were available for less than one year at the time of our study, with both gaps and inconsistencies in the available history. For the unoccupied and "to-be-built" units, no historical data are, of course, available, and we were obliged to use a mix of modeling techniques to estimate likely consumption and production patterns from the available information, together with reasonable assumptions based on our own best judgment and recommendations of the project team.

The approach we have taken is to model the energy performance of the UC Davis West Village community as it would perform during a single, hypothetical full year of "steady state" operation, in which all buildings have been constructed and are occupied over the course of the year, according to their anticipated use and normal weather and occupancy patterns. We call this representation of load a "synthetic year", as it represents an ahistorical baseline state against which to evaluate future performance.

In reality, all aspects of the community will continue to evolve and change over time, with a dynamic level of tenancy, occupancy, and usage for all the building types. For example, with the high rate of turnover of students in the rental housing, and the arrival of increasing numbers of faculty and staff in the Faculty Staff housing, it is likely that UC Davis West Village will see changes in end-use behavior each year, as each new crop of residents arrives with more and different electronic devices, appliances, and perhaps EVs. At the same time, educational outreach efforts by WVCP may be expected to help improve energy awareness and reduce consumption by continuing residents over time.

Our aim in structuring a baseline approach was to provide a single unifying framework for representing the energy performance of the UC Davis West Village community that we believe can be extended and adapted as new and better data become available. Given the limitations of the existing data and the evolving state of construction and occupancy, we caution against taking any specific numerical model result below as authoritative. Rather, we believe our results and recommendations are best viewed as directional guideposts – identifying the best opportunities for further investment in monitoring and control capability to both improve the data and drive better energy decision making for UC Davis West Village.

1.4 Project Scope

GE Energy Consulting was engaged as the subcontractor for the UC Davis West Village Energy Initiative CSI RD&D project under Target Area 1, Task 2, entitled: "Integration of AMI with Solar PV and other DER Technologies". The scope of this Task consists of two main Subtasks:

- Subtask 1: Understand baseline energy performance for the existing and planned new construction buildings at UC Davis West Village, which include multi-tenant housing, commercial/public space, and Faculty Staff housing, and determine baseline performance against the objective of ZNE; and
- Subtask 2: Recommend the functional specification for a monitoring and control systems architecture that integrates the customer demand side ("AMI") with solar PV production and other DER technologies, to be able to measure and adjust performance against the ZNE goal on a dynamic, on-going basis.

1.4.1 Subtask 1

Under Subtask 1, GE's scope included the following activities:

- Collect, validate, and analyze existing and available data for UC Davis West Village
- Develop realistic assumptions for additional parameters, as necessary
- Develop a quantitative framework representing energy generation from solar PV at UC Davis West Village and energy consumption by end use
- Characterize expected baseline performance, including the physical attributes of each technology and behavioral sensitivities for user-controlled characteristics

The key deliverable from Subtask 1 is a baseline model of the energy performance of the UC Davis West Village Energy Initiative. This model is contained in the Excel Workbook submitted with this report and is documented extensively in Section 2 below. The Model

organizes UC Davis West Village according to the existing and future building types, allowing an estimation of the annual net energy performance for a hypothetical "synthetic year" of baseline operation.

1.4.2 Subtask 2

Based on the model developed in Subtask 1, GE then looked at ways to leverage demand side controls ("AMI") and other alternatives to enhance the energy performance capability of UC Davis West Village.

Under Subtask 2, GE's scope was to develop a Functional Specification for the integration of AMI, PV, demand response, and storage[9] technologies, consisting of:

- Recommendations for the IT and communications architecture (functional, not vendor-specific) to support the ZNE goal
- Estimated costs and benefits of incremental hardware and software
- Expected benefits of incremental control capability
- Summary of any additional design considerations, such as user friendliness, interoperability, potential electrical system, environmental, or aesthetic impacts, etc.

The key deliverable for this Subtask is the functional specifications with recommendations for incremental monitoring and control contained in Section 3 of this report.

[9] Energy storage technologies were originally included as part of the scope for Subtask 2. After further consultation with the UC Davis team and examination of the multiple challenges to be overcome, GE concluded that stationary battery (or other) energy storage was not currently a cost-effective resource option at West Village, due to both technical and economic constraints. In particular, as discussed below in Section 3.5.3, the nature of the annual Zero Net Energy goal provides no direct financial incentive for time-shifting of energy, for example, storing daytime-peaking PV generation to meet peak demand in the afternoon and evening hours. Technical barriers to the integration of storage are being examined elsewhere within the West Village CSI grant. GE recommends that storage options be evaluated at a later stage of the overall CSI project, when results of this pilot project become available.

2 Subtask 1

2.1 Subtask 1 Introduction

Subtask 1 is the development of a baseline model of energy performance for each building type at UC Davis West Village and seeks to answer the first of our key questions: How do we know if we are meeting ZNE? While limitations in the existing data make it impossible to determine definitively how the community is currently performing, our results permit some general inferences and provide guidance, based on the relative performance of each building type. The model we have developed can and should be adopted and further refined with the addition of new and better data as they become available in the near future.

2.2 Data Collection, Validation, and Analysis

2.2.1 Preliminary Data Analysis

We considered different data sets for review and analysis in order to determine the type of baseline model to develop. The main data challenges we encountered included the following:

- The wide mix of existing buildings with partial historical data (Ramble Phase 1, Viridian, Rec Center, MU) and to-be-built (Solstice, Ramble Phase 2, Faculty Staff Housing).
- PG&E consumption data for each existing unit were available for the last 9 months only. For different units, SunPower production data history varied from 1 to 9 last months, typically 5 months.
- Unknown occupancy patterns, future tenancy/commercial use.
- Anecdotal information that student load shapes are highly unusual, with some units experiencing very low afternoon and evening load but daily peaks that occur as late as midnight[10].
- Incomplete end-use breakdown in each unit and building.
- PG&E monthly bill history (Net metered) and SunPower hourly production and consumption data needed to be reconciled.

[10] While these observations were made from the SunPower consumption data that later proved unreliable, we were able to confirm similar behavior at other universities through conversation with utility load research experts at PG&E and other utilities.

- Limited access to hourly interval data (only one week of SunPower history downloadable at a time).
- SunPower consumption data appeared to be anomalous; software errors were later confirmed (see below).
- Unknown size and usage of future plug-in electric vehicle fleet.

We considered different data sets for review and analysis. The principal sources provided to us by WVCP included:

- UC Davis West Village Community Plan and Related Files
    - Ramble Apartments: 100% CD UC Davis West Village Student Housing Phase 1.pdf
    - Mixed-Use Buildings: MU1-MU6 University Approved (Complete).pdf
    - Solstice Apartments: 01-Gen.pdf, 08-Electrical.pdf
    - Single Family Houses: WV Single Family Floor Plans 022912.pdf
    - Lease and Recreation Center: 100% CD UC Davis West Village Square Leasing & Rec.pdf
    - UC Davis West Village Student Housing Phase 1.pdf
    - Mixed Use Commercial Space Energy Budget_Analysis_07112012.pdf
- Solar PV Inventory
    - SunPower UCD checklist Master List.xlsx
- PG&E Billing
    - Davis electrical tracking 2012 trueup v25 ~9-17 w' daily use.xls
- Hourly SunPower Data
    - Download of a several months of daily and a week of hourly SunPower Production and Consumption Data
- Davis Energy Group report (covering Mixed-Use)

The monthly PG&E data provided the “net” kWh consumption at each meter, which is the total electricity consumption minus the total solar electricity generation measured at each unit’s meter. The net kWh consumption can be positive or negative depending on the

relative values of electricity production and consumption over the course of the PG&E billing cycle month[11].

SunPower, which installed and monitors the solar facilities at UC Davis West Village, provided access to monitoring data from both the inverter (solar production) and a consumption measurement derived from a Current Transformer clamp installed at the individual unit junction box[12]. The SunPower data included both monthly Solar PV electricity production and cumulative monthly electricity consumption for each unit. The hourly interval SunPower data are not stored, and can only be downloaded manually for the previous 168 hours at the time of the download.

After manual download at two different occasions, we analyzed the hourly SunPower electricity production and consumption data, and compared it to the PG&E net energy data.

We quickly observed that the hourly SunPower consumption data were inaccurate, and were correlated with solar production.[13] This anomaly was later confirmed by SunPower[14], which is working to correct an apparent software bug in its monitoring user interface. Hence, we decided to build a bottom up Monthly/Annual Model of UC Davis West Village Electricity Production and Consumption. The model builds up consumption from estimates of individual end use loads, without calibration against a total metered load for each unit. By "bottom up" we mean that the model starts with each individual unit production and consumption presentation and representation of individual end-use and then builds up and sums up the total community energy production and consumption from there as long as the relevant information is available or can be represented.

The following tables provide examples of the raw PG&E and SunPower data.[15]

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[11] PG&E calculates and delivers monthly bills based on a rolling monthly cycle of read dates that varies from account to account. GE was able to identify the read cycle calendar for the UC Davis West Village units and weight the SunPower data (which is on a calendar basis) from the previous and current month in order to approximate an equivalent to the PG&E cycle month.

[12] This CT clamp measures an instantaneous "pulse" of power flows into the unit at periodic intervals and then averages the power (instantaneous current times voltage) over the intervals in an hour to obtain an estimate of energy consumed (kWh) during the hour. This method is inherently less accurate than the utility grade metrology used by PG&E.

[13] While cooling energy usage would normally correlate well with solar production, the correlation witnessed in the data is much stronger than cooling alone would explain.

[14] Conversation with Josh Kozub, Manager, Operations & Maintenance, Residential Systems North America, SunPower Corporation

[15] In these and all subsequent tables, individual unit addresses are concealed in order to protect the privacy of residents.

			Dec - 2011		Jan - 2012		Feb - 2012		March - 2012	
address	unit #	beds	Amount Billed	Billed Usage	Amount Billed	Billed Usage	Amount Billed	Billed Usage	Amount Billed	Billed Usage
XYZ Sage	a	4	$ 16.57	166	$ 28.75	283	$ 37.89	355	$ 32.77	308
XYZ Sage	b	3	$ 31.97	324	$ 37.30	369	$ 72.53	693	$ 50.54	484
XYZ Sage	c	3	$ 30.14	304	$ 65.72	659	$ 55.11	528	$ 51.52	492
XYZ Sage	d	4	$ 10.88	108	$ 6.32	60	$ 43.86	415	$ 15.43	140
XYZ Sage	e	4	$ 44.12	442	$ 84.36	848	$ 90.23	856	$ 68.35	652
XYZ Sage	f	3	$ 12.10	121	$ 5.18	49	$ 29.92	284	$ 19.79	185
XYZ Sage	g	3	$ 23.91	241	$ 23.52	235	$ 33.86	321	$ 22.80	210
XYZ Sage	h	4	$ 17.08	171	$ (6.25)	-69	$ 22.25	207	$ 1.26	5
XYZ Sage	i	4	$ 21.61	215	$ 39.01	382	$ 56.03	534	$ 86.16	831
XYZ Sage	j	3	$ 23.66	235	$ 38.90	382	$ 33.84	317	$ 1.33	7
XYZ Sage	k	3	$ 11.20	112	$ 2.79	23	$ 29.25	276	$ 15.44	142
XYZ Sage	l	4	$ 21.08	212	$ 5.13	48	$ 30.46	289	$ 21.45	199
XYZ Sage	house a - l	#B	$ 94.44	480	$ 81.44	600	$ 202.71	960	$ 38.69	360

Table 1: Example of PG&E Data

Address	Bldg	Unit	City	Zip Code	WattNode #	Inverter #	Inverter Model #	PV Supervisor	Module Type	Count	Status
XYZ Sage Street	Building A	a	Davis	95616	64509	2001603177	SPR-4000M	TAAE01081098	SPR-425E-WHT-D	10	Completed
XYZ Sage Street	Building A	b	Davis	95616	64500	2001660433	SPR-3000M		SPR-425E-WHT-D	8	Completed
XYZ Sage Street	Building A	c	Davis	95616	64897	2001688033	SPR-3000M		SPR-425E-WHT-D	8	Completed
XYZ Sage Street	Building A	d	Davis	95616	64501	2001597624	SPR-4000M		SPR-425E-WHT-D	10	Completed
XYZ Sage Street	Building A	e	Davis	95616	64803	2001031323	SPR-5000M		SPR-225E-BLK-D	21	Completed
XYZ Sage Street	Building A	f	Davis	95616	64889	2001603362	SPR-4000M		SPR-225E-BLK-D	18	Completed
XYZ Sage Street	Building A	g	Davis	95616	64901	2001572176	SPR-4000M		SPR-225E-BLK-D	16	Completed
XYZ Sage Street	Building A	h	Davis	95616	64499	2001603333	SPR-4000M		SPR-225E-BLK-D	18	Completed
XYZ Sage Street	Building A	i	Davis	95616	64893	2001603450	SPR-4000M		SPR-225E-BLK-D	18	Completed
XYZ Sage Street	Building A	j	Davis	95616	64882	2001603175	SPR-4000M		SPR-225E-BLK-D	18	Completed
XYZ Sage Street	Building A	k	Davis	95616	64842	2001603111	SPR-4000M		SPR-225E-BLK-D	16	Completed
XYZ Sage Street	Building A	l	Davis	95616	64888	2001603245	SPR-4000M		SPR-225E-BLK-D	18	Completed
XYZ Sage Street	Building A	Common Area	Davis	95616	78881	2000960934	SPR-6000M		SPR-425E-WHT-D	15	Completed
XYZ Sage Street	Building A	Common Area	Davis	95616		2000973875	SPR-6000M		SPR-425E-WHT-D	15	Completed
XYZ Sage Street	Building A	Common Area	Davis	95616		2000973753	SPR-6000M		SPR-425E-WHT-D	15	Completed

Table 2: Example of SunPower Solar PV Inventory

2.2.2 Data Validation and Analysis: Solar Production

The following figures depict plots of daily solar PV production (from SunPower) for selected units.

The first figure includes a number of 3 bedroom units covering about 7 months of data. A clear seasonal pattern can be observed; however, there appear to be many wide swings of data. To the extent that deep sags appear to be correlated across all units for a given day, one can surmise the cause to be the daily variations in weather and cloud formation, but that does not seem to be the case in most instances.

There are a number of dips that are followed immediately by spikes in the following day's data, which we hypothesize to be the result of a communication error and a failure to report production during certain hours (which then gets added to the next day's production data). This pattern appears to explain many of the anomalous data points and could be corrected by averaging or "smoothing" the daily data.

The wide range of produced energy for different apartments shown in the same figure also indicates that different 3 bedroom apartments are connected to different panel array sizes.[16] In fact, there are about ten different ratings for the 3 bedroom apartments' panels, ranging from 3.2kW to 4.2kW. Some of the 4 bedroom apartments are connected to panels of similar ratings.

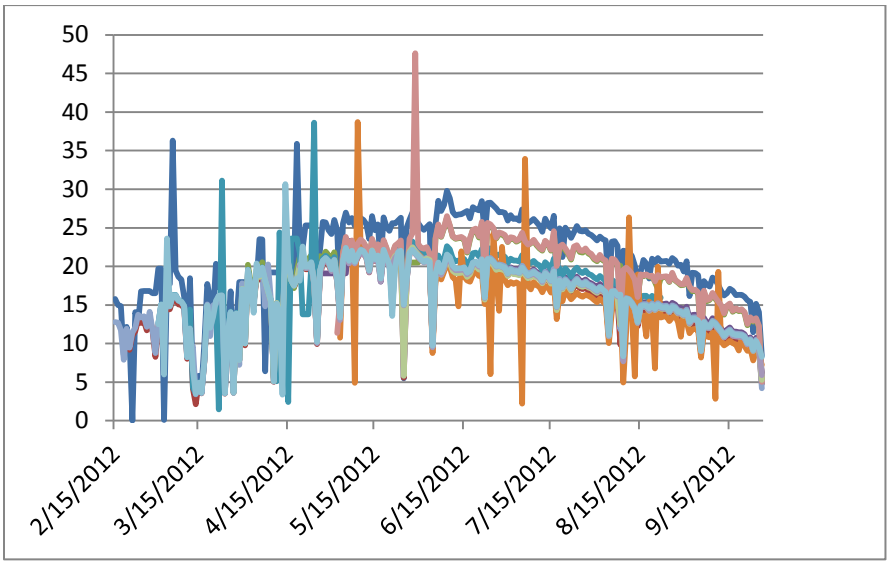

Figure 4: Daily Solar Production of Selected 3BR Ramble Units in kWh

The second figure includes three curves, each an average over sets of representative units of 2, 3, and 4 bedroom apartments, respectively. Here we observe a higher level of correlation of variations across the solar generation of different unit types ("dips" with none of the sag/spike pairs), and hence, one can assume the cause to be daily variations in solar activity and cloud formation. As might be anticipated, cloudy days appear more frequently in the spring months than in the peak summer season (which in sunny Davis may extend all the way through September and even October).

[16] In addition to differences in array size, there are also some variations in PV system orientation and azimuth among the buildings in UC Davis West Village.

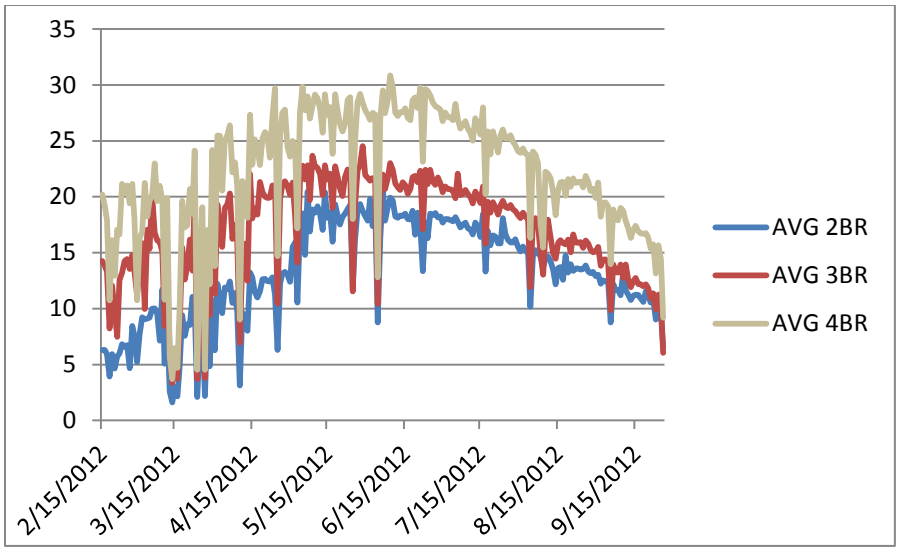

Figure 5: Average Daily Solar Production for 2, 3, and 4 BR Units in kWh

The wide variation in actual SunPower data across units and also across time led us to seek a more standard and weather normalized way to represent the average solar power during different years. As recommended to us by SunPower[17], we investigated the NREL PVWatts™ Calculator (PVW), a public domain web-based tool to generate the monthly normalized PV data. Using PVW, we are able to extrapolate production for all months of the year.

Using PVW, we determined the monthly kWh generation for a 1 kW PV panel for the Sacramento area (the closest weather station site to the Davis area available in PVW). We then calculated each individual unit's or aggregate unit's monthly solar PV production in kWh by scaling the monthly NREL PVW data (given for 1 kW PV Panel) using the individual unit's or aggregate unit's PV Panel Nameplate kW values provided in the SunPower data.

To verify the reasonableness of the PVW data, we compared the monthly PVW data with actual SunPower recorded data for a number of Phase 1 units, for the months for which actual data were available. Results are show in the following table and chart.

[17] Conversation with Josh Kozub, Manager, Operations & Maintenance, Residential Systems North America, SunPower Corporation

	PVW 3.4kW	Unit A	Unit B	Unit C	Unit D	Unit E	PVW 3.6kW	Unit F	Unit G	PVW 4.05kW	Unit H	Unit I	Unit J	Unit K
January	**150**						**158**			**178**				
February	**223**						**237**			**266**				
March	**360**		357	369		366	**381**			**429**	449		525	183
April	**478**	525	524	538		534	**506**	550		**570**	633		655	269
May	**583**	644	623	648	652	635	**617**	666	686	**695**	759	763	757	316
June	**600**	592	579	624	548	592	**635**	705	708	**714**	794	797	792	305
July	**614**	578	552	612	519	571	**650**	694	699	**731**	771	770	789	295
August	**555**	470	439		423	465	**588**	579	579	**661**	641	645	700	243
September	**439**						**465**			**523**				
October	**316**						**335**			**377**				
November	**178**						**189**			**212**				
December	**134**						**142**			**159**				
Correlation		0.5195	0.7972	0.9645	0.3992	0.8346		0.9151	0.9014		0.9627	0.8761	0.9892	0.8841

Table 3: Comparison of PVW and SunPower Data

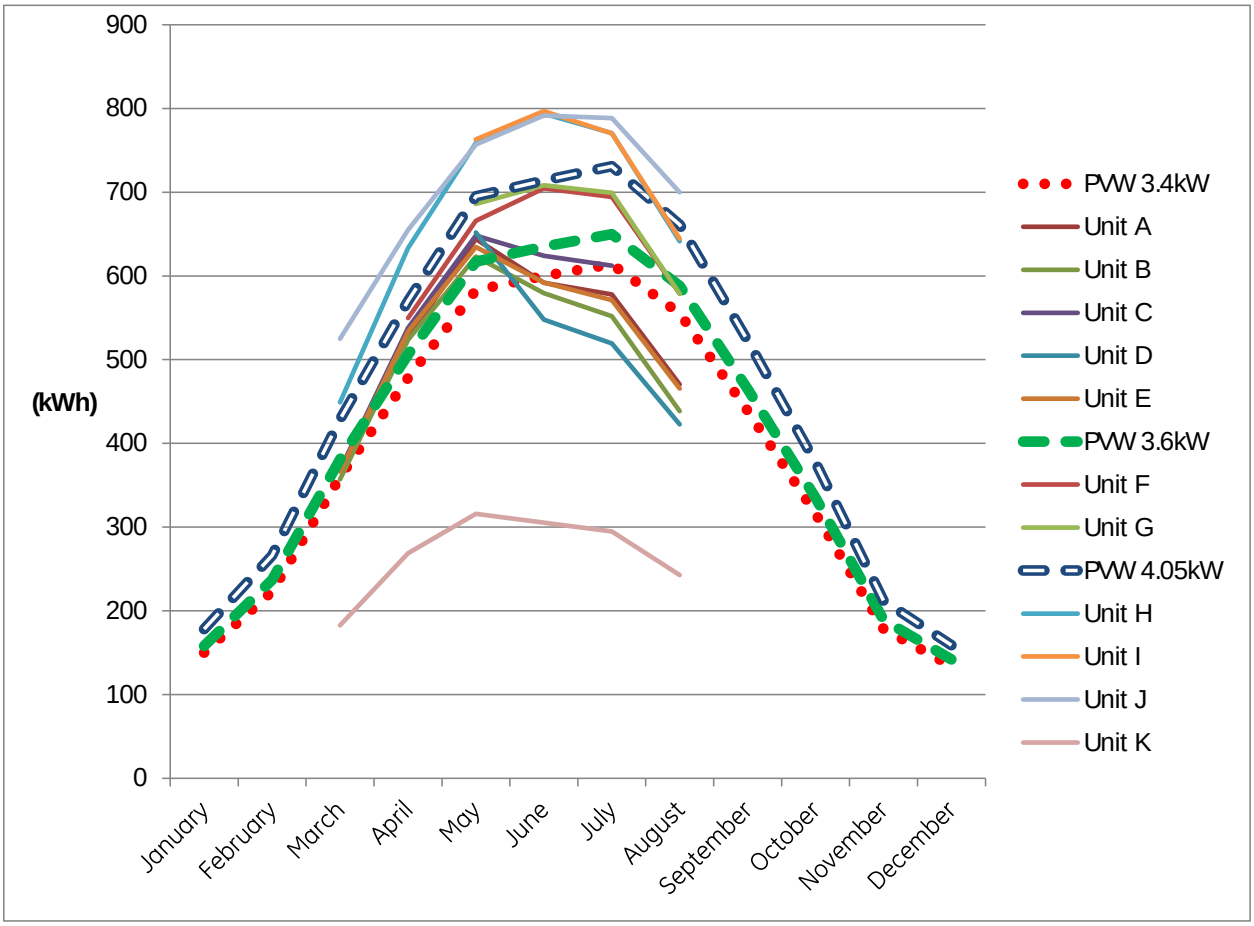

Figure 6: Comparison of PVW and SunPower Data

As can be observed, the PVW data provide a reasonably good match to the actual but incomplete monthly SunPower recorded data. The outlying SunPower data for the last unit is

most likely due to incorrect assumption about the size of the solar panel, and should be ignored. Moreover, the PVW data are already "weather normalized" based on many years' of Sacramento area weather data and should therefore be a more representative and reliable predictor of solar output for our "synthetic year" baseline than the observed pattern of data for just spring-fall 2012.

In the future, as actual historical data becomes available for a longer period through on-going collection and recording of SunPower data, the PVW data can be replaced with more UC Davis West Village specific data.

The monthly PVW data for a 1 kW panel for a Sacramento location is given in the following table. For simplicity in running the PVW calculator, we assumed a South facing system orientation with 180-degree Azimuth (flat).[18]

kW	Month	Solar Radiation (kWh/m2/day)	AC Energy (kWh/Month)
1.0000	1	1.87	44
	2	2.98	66
	3	4.28	106
	4	5.92	141
	5	7.20	171
	6	7.83	176
	7	7.88	181
	8	7.08	163
	9	5.75	129
	10	3.96	93
	11	2.33	52
	12	1.73	39
	Year	4.91	1,362

Table 4: PVW Monthly Solar Electric Energy Used for Electricity Production Calculations

[18] In reviewing the detailed solar drawings, several of the buildings in UC Davis West Village appear to have a different solar orientation, however, a quick sensitivity check suggests that differences in solar production due to orientation are only on the order of 3%.

2.3 WV Electricity Production and Consumption Model

This section describes the approach we selected to construct a baseline model of UC Davis West Village electricity production and consumption based on the currently available data. Because the model was built without calibration against historical consumption data, the results are highly sensitive to specific input assumptions.

To keep the model accessible to future developers, we intentionally did not include any macros. All the operations are based on cell-based formulas that can easily be viewed. Cell to cell linkages can be viewed through "Formula Auditing" using "Trace Precedents" and "Trace Dependents". This is a stand-alone model with all the data self-contained and no links to additional files.

Areas for future improvement may include updated modeling of various components and modules of the model such as specific formulas for electricity consumption of appliances, lighting, heating, and cooling. In addition, as the UC Davis West Village community is expanded and new residential and commercial units are built, the [Model Main] worksheet can be expanded by replacing the aggregated representation of future developments with fully disaggregated representation similar to Phase 1 units.

More complexity can also be incorporated into the model in the future by "agent-based" representation of electricity usage in each unit, reflective of different behavior patterns and occupancy, with underlying stochastic/probabilistic features.

2.3.1 Model Features

The main features of the model are:

- We estimated each unit's PV electricity production
    - Based on each unit/building's kW PV capacity and the NREL PVW monthly solar electricity production projections.
- We estimated each unit's electricity consumption
    - Based on each unit's electricity consumption for appliance use, heating, cooling, and lighting, as well as miscellaneous plug loads (the model accounts for the plug loads in addition to the appliance load).
- We made assumptions for missing data.
- We modeled all existing Ramble and Viridian units individually
- We modeled all Solstice and Ramble Phase 2 units as aggregates grouped by number of bedrooms

- We modeled all Single-Family Homes as aggregates grouped by type of floor plan/area
- We modeled all Single-Family Home Studios aggregated into one group
- We included all Mixed Use Commercial, Lab Space, Café-Restaurant-Grocery shops based on modeling from the Davis Energy Group report
- We included the Recreational Center and Leasing Office (Club + Gas accounts) using projection/estimation of their energy use based on the available months of PG&E bills

2.3.2 Structure of the Model

The UC Davis West Village Monthly Electricity Production and Consumption Model (the "Model"), is an Excel spreadsheet that projects monthly electricity production and consumption for existing individual units and future aggregate units.

The main Excel Model Workbook includes the following worksheets (tabs):

- [Results Summary]: This worksheet contains tables of results by *Individual Unit Type Categories* and also by *Aggregate Unit Type Categories*.
- [Model Main]: This worksheet is the main module of the model where all the individual and aggregate units are listed and the final layers of production and consumption data are calculated. Section 2.3.3 below provides more detail on various components of this module.
- [Unit Data]: Includes unit type and area data for current and future phases.
- [Appliance Data]: Includes appliance data by building type, and lighting, heating, and cooling energy consumption assumptions.
- [HVAC Data]: Includes the main assumptions and approach to determine the annual heating and cooling electricity consumption per unit of area.
- [Pattern Data]: Includes Seasonality, Occupancy Type, and other tables used in calculation of electricity consumption.
- [Mixed Use Data]: Includes electricity consumption data of Mixed Use units based on information provided by the Davis Energy Group Report.
- [Club & Gas Data]: Contains the methodology used to project the electricity consumption of the Rec and Lease Office and swimming pool pump load.
- [PG&E Data]: Contains the PG&E Billing Statement data used to identify individual units and obtain PG&E Metered Net Energy Data.
- [SunPower Data]: Contains the unit by unit SunPower information on solar PV panel ratings.

- [PVW Data]: Includes NREL PVWatts ™ Calculator data on monthly Solar PV Power Output of 1kW Solar Panel sited in the Sacramento region.
- [PVW Analysis]: Provides a comparison of PVW data and SunPower data in order to justify using of PVW.
- [SunPower Phase 2 PV Data]: Includes the data from SunPower used to determine the Solar PV Electricity production of Phase 2 Ramble units.
- [SunPower Club & Gas Data]: Contains the daily SunPower energy production data that is used to determine the monthly Club & Gas electricity consumption for available months.
- [Compare GE PG&E]: This worksheet provides a comparison of GE model output of monthly unit electricity consumption with actual unit electricity consumption calculated based on the sum of SunPower monthly electricity production and PG&E Net Energy data.

2.3.3 Components of the [Model Main] Worksheet

The [Model Main] worksheet performs the main calculations of electricity production and consumption of the UC Davis West Village community.

2.3.3.1 Electricity Production and Consumption

- The electricity production values are calculated using PV kW ratings from the relevant architectural design specs and monthly PVW Data.
- The electricity consumption values are based on electricity consumption by (a) Appliances (including Miscellaneous Plug Loads), (b) Lighting, (c) Cooling, and (d) heating. Each of these electricity consumption components are described in later sections.

2.3.3.2 Individual versus Aggregate Units

Individual and aggregate unit identifications and unit by unit monthly and annual electricity production and electricity consumption are provided and calculated in the [Model Main] worksheet.

Residential, commercial, and recreational units are grouped into “individual” and “aggregate” units.

- Individual Units: These are units which (a) could be identified individually, and (b) for which electricity production and consumption could be calculated on a unit by unit basis. The individual unit information and data are provided in the first few hundred rows. The Individual units list includes:

  - All Phase 1 Ramble and Viridian Apartments (both electricity production and consumption)
  - Mixed Use Retail and Common Area electricity production only
  - Club and Gas components of the Club House (Recreation and Leasing Center plus outdoor pool pumping load) for electricity production only
- Aggregate Units: These are buildings that could not be disaggregated into individual units, and hence, the electricity production and consumption are calculated for the aggregate whole. The aggregate unit information and data are provided further down the table in a section after listing of all the individual units. The Aggregate Unit list includes:
  - Mixed Use Retail and Common Area electricity consumption within the Viridian and Phase 1 Ramble buildings.
  - Club and Gas components of the Club House for electricity consumption only
  - EV Fleet under "Other-Use-EV Fleet"
  - Single-Family Homes
  - Solstice and Phase 2 Ramble units

The reason for separate treatment of the Mixed Use Retail and Club House is that their electricity consumption calculation does not fit into the methodology used for calculation of electricity consumption of individual units, although their electricity production calculation does.

2.3.3.3 Description of columns in the [Model Main] Worksheet

- Columns A to H: These columns contain reference codes that identify a particular unit within the model, based on the combination of various unit related codes. These cells should not be altered, since they are referenced by other cell formulas.
- Columns I to L: These columns include data from PG&E statements that include unit building type, unit address, unit number, and unit bedroom numbers or other identification codes. All the individual "existing" (built and occupied at the time of our study) units have been included.
- Columns M to O: These columns include unit information from SunPower that are matched to PG&E unit information including unit address, unit building, and unit number.
- Columns P to AD: These columns calculate the monthly and annual PV electricity production in kWh. Column AC shows the Capacity Factor (defined as the ratio of

total energy produced to total potential energy if the PV was producing at full capacity at all hours of the day for the year).

- Columns AE and AF: These columns are, again, coded values used in later columns to search for values and should not be altered.
- Column AG: Area of the Unit/Building Component in Square Feet. The underlying formulas pull data from the [Unit Data] worksheet. Unit Area is used in the calculation of Lighting, Cooling, and Heating electricity consumption, but does not impact Appliance electricity consumption (Appliance usage is modeled as a function of the occupancy, rather than as a function of floor space within a given unit).
- Column AH: Occupancy Type, which is defined in the worksheet [Pattern Data]. Occupancy Type impacts Appliance, Lighting, Cooling, and Heating electricity consumption. Occupancy types are described later in the section on [Pattern Data] worksheet.
- Columns AI to AU: These columns calculate the monthly and annual "Appliance" electricity consumption. The underlying formulas in the cells pull data from the [Unit Data], [Appliance Date], and [Pattern Data] worksheets. Appliance electricity consumption depends on the Occupancy Type, but does not dependent on the Unit Area.
- Columns AG to BH: These columns calculate the monthly and annual "Lighting" electricity consumption. The underlying formulas in the cells pull data from the [Unit Data], [Appliance Data], and [Pattern Data] worksheets. Lighting electricity consumption depends on both the Occupancy Type and also on the Unit Area.
- Columns BI to BU: These columns calculate the monthly and annual "Cooling" electricity consumption. The underlying formulas in the cells pull data from the [Unit Data], [Appliance Data], [HVAC Data] (indirectly), and [Pattern Data] worksheets. Cooling electricity consumption depends on both the Occupancy Type and also on the Unit Area.
- Columns BV to CH: These columns calculate the monthly and annual "Heating" electricity consumption. The underlying formulas in the cells pull data from the [Unit Data], [Appliance Data], [HVAC Data] (indirectly), and [Pattern Data] worksheets. Heating electricity consumption depends on both the Occupancy Type and also on the Unit Area.
- Columns CI to CV: These columns sum up total monthly and annual electricity consumption from Appliance, Lighting, Cooling, and Heating columns.
- Column CW: This column contains the total PV Electricity Production.
- Column CV: This column contains the total Electricity Consumption.

- Column CY: This column provides the Consumption to Production ratio. A ratio of 1 would represent "Zero Net Energy" over the course of our synthetic year. A ratio less than 1 represents Production greater than Consumption – a better than ZNE performance that may be counted against usage elsewhere in the community. A ratio greater than 1 represents Consumption greater than Production or a net energy performance above ZNE for the year.
- Column CZ: This column provides the Production to Consumption ratio, which is the inverse of the value of the previous column.

The total annual electricity production and consumption values and their ratios are given in the last row under columns CW, CV, CY, and CZ.

2.3.3.4 Calculation of Electricity Production

Electricity production is based on the Solar PV panel power rating assigned or estimated for each individual or aggregate unit. The SunPower Data identifies the panel "module type" for each individual unit in Phase 1 and Phase 2, and also for other Phase 1 non-residential units such as "Retail" and "Common" and "Club" and "Gas" units identified in the [Model Main] worksheet under the "individual unit" category. The Phase 1 and Phase 2 PV name plate ratings are from SunPower. The PV data for the Solstice are from architectural design drawings. The Single Family PV data is based on scaling of Phase 2 data using area proportionality of total Single Family unit areas to total Phase 2 unit areas.

2.3.3.5 Calculation of the Electricity Consumption

Except for the Club House and the Mixed Use Retail and EV Charging, the model divides the electricity consumption into the following 4 classes:

a) Appliances (including Miscellaneous Plug Loads)

b) Lighting

c) Cooling

d) Heating

2.3.3.6 Appliances

Appliance assumptions are provided in the [Appliance Data] worksheet for Viridian and Ramble/Solstice type unites. The appliance kW ratings were taken from UC Davis West Village documents. Reference page numbers of the source are provided in [Appliance Data] worksheet.

- Dishwasher
- Disposer

- Range
- Dryer
- Kitchen Small Appliance
- Microwave
- Refrigerator
- Clothes Washer
- Miscellaneous Plug Loads (e.g. televisions, laptops, stereos, gaming consoles, etc.)

We assumed Miscellaneous Plug Loads to be 10% of the total appliance load.

We made a number of assumptions for "Minute per Cycle" and used available DOE values[19] for average "Cycles per Year" for some of the appliance types, and where no DOE values were available, we used our own assumptions to assign "Cycles per Year" for remaining appliance types. Furthermore, we assumed that the base case appliance data applies to a 4BR unit. For differently sized units, the model scales the appliance electricity usage using scaling factors from a table of Appliance Multipliers defined in the [Pattern Data] worksheet.

In the model, the Appliance kWh per Month of each unit is calculated by using the following variables in the underlying formulas in the [Model Main] cells under the monthly Appliance columns:

- Annual kWh/Year scaled based on number of days in each month – under "Seasonal" table in [Pattern Data] worksheet.
- Number of Units (1 for individual units, and greater than 1 for aggregate units)
- Occupancy Types of A, B, C, or D, as defined in "Occupancy" table in [Pattern Data] worksheet.
- Scaling by Number of Bedrooms, as defined in "Appliance Multiplier" table in [Pattern Data] worksheet.

The data tables in the [Pattern Data] are described in a later section.

2.3.3.7 Lighting

The lighting data is defined in [Appliance Data] worksheet. We have assumed a linear relationship between lighting electricity usage and area plus a fixed value (i.e., 1.22 Watts/SF

[19] "Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves - Cost/Benefit Analysis REPORT", Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830 Pacific Northwest National Laboratory, Richland, Washington 99352, December 2010.

+ 125 Watts), based on the California Standards[20]. Lighting electricity usage of each unit is calculated by using the following variables in the underlying formulas in the [Model Main] cells under the monthly Appliance columns:

- Lighting equation of 1.22 Watts/SF + 125 Watts
- Area of each individual unit or aggregate units
- Monthly hours of lighting, as shown in "Seasonal" table in [Pattern Data] worksheet, based on hours in each month and the Daily hours of lighting by season, as defined in "Daily Hours" table in [Pattern Data] worksheet.
- Number of Units (1 for individual units, and greater than 1 for aggregate units)
- Occupancy Types of A, B, C, or D, as defined in "Occupancy" table in [Pattern Data] worksheet.

2.3.3.8 Cooling and Heating

Annual Cooling and Heating Electricity Usage

The cooling and heating data originate from the data defined in [HVAC Data] worksheet. The approach used was to determine an average kWh/SF-Year value for cooling and heating representative of the Sacramento cooling and heating requirements and reflective of the UC Davis West Village community building set-ups. Due to lack of detailed available data on actual cooling and heating needs in general and in UC Davis West Village community in particular, we used a public domain web-based tool (i.e., HVACOPCOST.COM) to project the cooling and heating needs (i.e., electricity consumption) of the UC Davis West Village community.

Since this was a small-scale project, which imposed limits on resources for the development of the model, the approach described below should be considered as a first order approximation for estimating the size of heating and cooling in the community. Future steps in improving the model could include a more detailed modeling of heating and cooling using ASHRAE data and standard heating/cooling degree-day or bin methods, which would require more time and effort beyond the scope of the current project.

To determine Heating and Cooling Requirements in kWh/SF-Year we used the web-based tool to determine the cooling and heating equipment size for the Sacramento region and

[20] "2013 California Building Energy Efficiency Standards, California Utilities Statewide Codes and Standards Team", March 2011.

calculate the annual cooling and heating energy usage based on given parameters, based on the following steps:

- We first used the following web link to find the Cooling and Heating Degree Days for Sacramento
    - http://www.hvacopcost.com/
- We determined that the web-based calculator was not doing a proper job of also determining the optimal cooling and heating equipment size. Changing the unit area did not change the equipment size. However, the site provides specific degree day data for the Sacramento region:
    - Cooling Degree Days for Sacramento: 1,491
    - Heating Degree Days for Sacramento: 2,361
- We then used the following web link to determine the Cooling and Heating Equipment Size for cooling and heating regions with close to or similar degree days to Sacramento.
    - http://www.hvacopcost.com/equipsize.html
    - Cooling Degree Days for Selected Region: 1,402, Cooling Equipment Size: 2.00 Tons
    - Heating Degree Days for Selected Region: 2,942, Heating Equipment Size: 36,000 Btus
- Using the Sacramento specific cooling and heating degree days, and applying degree day proportionality (which means using ratio of degree days to scale the data), we calculated the following equipment size for the Sacramento region:
    - Cooling Degree Days: 1,491, Cooling Equipment Size: 2.13 Tons
    - Heating Degree Days: 2,361, Heating Equipment Size: 29,000 Btus
- We then went back to the following web link to enter the inputs for the Sacramento region.
    - http://www.hvacopcost.com/
- The following information was entered at the site (with Sacramento selected):
    - Unit Area: 1,000 SF
    - Cooling Degree Days: 1.491
    - Cooling Equipment Size: 2 Tons
    - Electricity Price: 1 Cents per kWh (to enable getting the equivalent kWh value instead of cost)

  - Cooling System Type: A/C Variable Speed
  - SEER: 15 (Source: 100% CD UC Davis West Village Student Housing Phase 1.pdf - Page 91)
  - Heating Degree Days: 2,361
  - Heating Equipment Size: 29,000 Btus
  - Fuel Price: 29.31 Cents per Therm (to get the equivalent kWh value instead of cost, since 1 Therm is 29.31 kWh)
  - Heating System Type: Heat Pump
  - HSPF: 8 (Source: 100% CD UC Davis West Village Student Housing Phase 1.pdf - Page 91)
- The Site Calculates the Following for Efficient Equipment:
  - Cooling High Efficiency Yearly Operating Costs $22.00
  - Heating High Efficiency Yearly Operating Costs $51.00
- However, these costs were calculated for a 1000 SF House
  - At 1 Cents/kWh:
    - The Cooling Energy Requirement is: 2.2 kWh/SF-Year
  - At 29.31 Cents/Therm (and 1 Therm = 29.31 kWh):
    - The Heating Energy Requirement is: 5.1 kWh/SF-Year

Scaling Factor to Take Into Account Building External Surface Areas

The last two final cooling and heating energy requirement numbers are pulled into the [Appliance Data] worksheet from [HVAC Data] worksheet, and are then scaled to reflect the difference between the topology of the UC Davis West Village buildings in comparison with individual stand-alone units.

The reasoning is that the Heating/Cooling kWh/SF-Year calculations are for a Stand-Alone Unit with 4 external walls and 1 Roof. However, UC Davis West Village buildings are combinations of 4-unit 3-story L-Shape and I-Shape buildings with total external surface areas less than same number of external surface areas for same number of stand-alone units. Fewer external surface areas means reduced heat transfer with outside and reduced total heating and cooling load compared to the same number of stand-alone units.

The model scales the total heating and cooling requirements of UC Davis West Village units by scaling the calculated heating/cooling requirements of stand-alone units.

Based on the shape of the buildings and number of units and floors in each building we compared total number of surface areas exposed to outside for selected number of UC Davis West Village buildings based on the numbers shown on UC Davis West Village architectural map, and compared it to the total exposed surface areas of the same number of stand-alone units. The calculation is provided in the [HVAC Data] worksheet. We determined a "rough" scaling factor of 63.54%, by which we multiplied the 2.2 kWh/SF-Year Cooling Energy Requirement and the 5.1 kWh/SF-Year Heating Energy Requirement. Result for UC Davis West Village Average is:

- The Cooling Energy Requirement is: 1.40 kWh/SF-Year
- The Heating Energy Requirement is: 3.24 kWh/SF-Year

Cooling and heating electricity usage of each unit is then computed by using the calculated cooling and heating energy requirements and the following variables in the underlying formulas in the [Model Main] cells under the monthly cooling and heating columns:

- Area of each individual unit or aggregate units
- Percentage of Cooling and Heating Electricity Usage by Month, as shown in "Seasonal" table in [Pattern Data] worksheet, based on hours in each month and the Daily hours of Cooling and Heating by season, as defined in "Daily Hours" table in [Pattern Data] worksheet.
- Number of Units (1 for individual units, and greater than 1 for aggregate units)
- Occupancy Types of A, B, C, or D, as defined in "Occupancy" table in [Pattern Data] worksheet.

2.3.4 Tables in [Pattern Data] Worksheet

The [Pattern Data] worksheet includes a number of tables that are used to define the monthly usage and occupancy patterns in the model. In the following tables taken from the [Pattern Data] worksheet, the values in cells that are colored brown are based on GE assumptions.

In the "Appliance Multipliers" table below, the total appliance electricity usage is scaled by a Scaling Factor based on the number of bedrooms in the unit. The reason is that the annual appliance electricity consumption evaluated in the [Appliance Data] worksheet is assumed to apply to a 4 bedroom unit. The appliance electricity usage is expected to be lower in units with fewer bedrooms, but the relationship between appliance electricity consumption and number of bedrooms in a unit is not considered to be proportional. The assigned multipliers, shown in the following table, although being the GE team's rough assumptions, are not based on any independent study. An example is the usage of clothes washer and dryer. A clothes-washer may be used almost the same number of the times during a week in 3 bedroom versus 4 bedroom unit, but the loading per cycle may be different. However, our

numbers could be conservative and overestimate appliance usage in units with fewer bedrooms.

APPLIANCE MULTIPLIERS	
Appliance Usage Multiplier by Number of Bed Rooms	
Bed Room	Multiplier
1	70%
2	80%
3	90%
4	100%

Table 5: Appliance Multipliers Based on Number of Bed Rooms

The "Daily Hours" table below is used to spread the total annual lighting, cooling, and heating load over different seasons of the year. These numbers are also GE team's rough estimates. Changing them will only re-allocate the monthly values of the total estimated annual electricity consumptions. If monthly usage is of interest, then these estimates should be revised based on further investigation.

DAILY HOURS			
	Lighting	Cooling	Heating
Spring	2.25	4	4
Summer	2.00	12	0
Autumn	2.25	4	4
Winter	2.50	0	12

Table 6: Daily Hours of Lighting, Cooling, and Heating by Season

The "Seasonal Pattern" table below draws from the preceding table to create the monthly electricity usage patterns. In case of appliance electricity consumption, the monthly differences are simply a reflection of different number of days in each month.

SEASONAL														
Season		Winter	Winter	Spring	Spring	Spring	Summer	Summer	Summer	Autumn	Autumn	Autumn	Winter	
Month		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
Month		1	2	3	4	5	6	7	8	9	10	11	12	
Days		31	28	31	30	31	30	31	31	30	31	30	31	365
Hours of	Lighting	77.5	70.0	69.8	67.5	69.8	60.0	62.0	62.0	67.5	69.8	67.5	77.5	820.8
Hours of	Cooling	0.0	0.0	124.0	120.0	124.0	360.0	372.0	372.0	120.0	124.0	120.0	0.0	1,836.0
Hours of	Heating	372.0	336.0	124.0	120.0	124.0	0.0	0.0	0.0	120.0	124.0	120.0	372.0	1,812.0
Percent	Appliance	8.5%	7.7%	8.5%	8.2%	8.5%	8.2%	8.5%	8.5%	8.2%	8.5%	8.2%	8.5%	100.0%
Hours of	Lighting	77.5	70.0	69.8	67.5	69.8	60.0	62.0	62.0	67.5	69.8	67.5	77.5	820.8
Percent	Cooling	0.0%	0.0%	6.8%	6.5%	6.8%	19.6%	20.3%	20.3%	6.5%	6.8%	6.5%	0.0%	100.0%
Percent	Heating	20.5%	18.5%	6.8%	6.6%	6.8%	0.0%	0.0%	0.0%	6.6%	6.8%	6.6%	20.5%	100.0%

Table 7: Seasonal Lighting, Cooling, and Heating

The "Occupancy Type" table below provides four occupancy alternatives:

- Type A: Full occupancy every month of the year.
- Type B: Partial occupancy during summer, e.g., some students stay in their residences to take summer courses or work in the area.
- Type C: Zero occupancy in the summer, e.g., some students leave for the summer.
- Type D: Zero Occupancy every month of the year, e.g., this pattern could apply to some unfinished building, even if the solar PV is functional and providing power to the grid.

In the current model, we have applied Type B occupancy across all units, individual or aggregate; however, in future versions of the model, different units can have different occupancy rates. Other occupancy patterns can be added to the table by inserting additional rows within the table.

OCCUPANCY TYPE														
Season		Winter	Winter	Spring	Spring	Spring	Summer	Summer	Summer	Autumn	Autumn	Autumn	Winter	
Month		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
Month		1	2	3	4	5	6	7	8	9	10	11	12	
Days		31	28	31	30	31	30	31	31	30	31	30	31	365
Full	A	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Partial 1	B	100.0%	100.0%	100.0%	100.0%	100.0%	60.0%	60.0%	60.0%	100.0%	100.0%	100.0%	100.0%	90.0%
Partial 2	C	100.0%	100.0%	100.0%	100.0%	100.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	100.0%	75.0%
Vacant	D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 8: Monthly Occupancy Type Patterns

2.3.5 Treatment of Club House

The solar PV electricity production of the Rec Center/Club House and its two components, i.e., Club and Gas, are based on the solar PV panel rating from SunPower data, and the monthly PVW data, which are provided within the Phase 1 rows of [Model Main] worksheet. The actual electricity consumption data covers only a few months. The [Club & Gas Data] worksheet contains the approach to project the Club House electricity consumption.

We used the actual production data from SunPower and PG&E data on net energy to construct the electricity consumption data, which cover a few months in the year (April to July of 2012 for Club, and April to June for Gas). We then extended the data to cover the whole year based on the following steps:

- JAN, FEB, MAR data based on APR Data.
- JUL Gas data based on ration of JUN Gas to Club Ratio.
- AUG Data based on JUL Data.
- SEP, OCT, NOV, DEC data based on APR Data.

The [Model Main] worksheet pulls in the constructed monthly Club and Gas electricity consumption data from the [Club & Gas Data] worksheet.

2.3.6 Treatment of Mixed Use Retail and EV Charging

The solar PV electricity production of the Mixed Use Retail units are based on the solar PV panel ratings from SunPower data, and the monthly PVW data, which are provided within the Phase 1 rows of [Model Main] worksheet. Due to lack of any actual data on Mixed Use Retail units, we relied on the Davis Energy Group Report of July 11, 2012 which provides an estimate of electricity usage in these units under a Low and a High electricity consumption scenario. We have retained the low and high estimates and also constructed an average estimate.

These estimates are contained in the [Mixed Use Data] worksheet (L109 to O117 Array). The data is pulled in by the [Model Main] worksheet for Mixed Use Retail units. We have selected the "High" electricity consumption scenario in the current model setting in the [Model Main] worksheet in the Mixed Use Retail group.

2.3.7 Treatment of Faculty Staff Housing Units

The main data for the Faculty Staff Housing Units are provided in the [Unit Data] worksheet under the "Faculty Staff Housing" heading. The Faculty Staff Housing comes in 4 types, and we are told all four types will be equally represented. We divided the expected 343 homes into 86, 86, 86, and 85 unit types of A, B, C, and D respectively.

In up to 206 homes, there will a separate studio units (in-laws, guests, or rental) built either above the garage, or on-grade.

To estimate the solar PV electricity production, we applied the Total PV kW Rating ratio to Total Area of Phase 2 Units to determine an average PV kW/SF for all of Faculty Staff housing. We then used the area by type of Faculty Staff housing to assign kW ratings for each unit type, including studios. We then applied the PVW monthly data to determine the monthly electricity production by each home type.

To project electricity consumption in the Faculty Staff Housing, we used the same approach as the one used for Phase 1 units, including the projection of appliance usage, lighting, heating, and cooling, as can be seen from the populated areas in the [Model Main] worksheet under the Faculty Staff Housing grouping.

2.3.8 Treatment of Phase 2 Ramble

The Phase 2 Ramble unit solar PV ratings are provided by SunPower for each individual Phase 2 units in [SunPower Phase 2 PV Data] worksheet.

The Phase 2 Ramble unit types, number of units, and unit areas are provided in the [Unit Data] Worksheet under the Phase 2 Ramble heading.

We used the total area by unit type to allocate PV kW ratings for each unit type in [Model Main] worksheet.

To project electricity consumption for the Phase 2 units, we used the same approach as the one used for Phase 1 units, including the projection of appliance usage, lighting, heating, and cooling, as can be seen from the populated areas in the [Model Main] worksheet under the Phase 2 grouping.

2.3.9 Treatment of Solstice

The Solstice unit types, number of units and unit areas are provided in the [Unit Data] worksheet under the Solstice heading.

The Solstice total solar PV ratings are based on the available data shown in [Unit Data] worksheet. We used the total area by unit type to allocate PV kW ratings for each unit type in [Model Main] worksheet.

To project electricity consumption for the Solstice units, we used the same approach as the one used for Phase 1 units, including the projection of appliance usage, lighting, heating, and cooling, as can be seen from the populated areas in the [Model Main] worksheet under the Solstice grouping.

2.4 Model Validation & Adjustment

We undertook a comparison of the model consumption results and actual consumption values from the available data. The actual consumption data are based on the sum of PG&E Net Metered Energy and SunPower Production values, as shown in the following table.

Consumption (kWh)	MAR	APR	MAY	JUN	JUL	AUG
Unit 2BD A	285	214	140	140	161	163
Unit 2BD B	405	322	305	325	315	359
Unit 2BD C			427	304	348	531
Unit 2BD D				420	430	732
Unit 2BD E				268	339	492
Unit 2BD F			216	222	309	260
Unit 2BD G				543	780	671
Unit 2BD H				309	147	231
Unit 2BD I			124	135	396	255
Unit 2BD J			150	291	405	427
Unit 2BD K						86
Unit 2BD L				89	27	32
Unit 3BD A	630	584	438	548	545	715
Unit 3BD B	451	454	494	559	829	627
Unit 3BD C	541	509	587	501	543	511
Unit 3BD D			837	805	839	979
Unit 3BD E		532	511	703	863	788
Unit 3BD F		462	531	641	633	608
Unit 3BD G		341	386	470	479	488
Unit 3BD H			542	607	713	743
Unit 3BD I			54	793		847
Unit 3BD J	378	311	297	293	322	
Unit 3BD K	304	364	303	395	184	390
Unit 4BD A	586	455	519	605	642	694
Unit 4BD B	479	339	277	396	408	353
Unit 4BD C	782	829	934	845	1,231	1,076
Unit 4BD D		473	486	524	388	695
Unit 4BD E			375	296	585	387
Unit 4BD F		657	561	703	619	645
Unit 4BD G	648	636	759	662	580	278
Unit 4BD H			437	407	468	404
Unit 4BD I	583	562	724	741	729	714
Unit 4BD J	702	503	428	453	463	424

Table 9: Actual Historical Consumption Data (PG&E Net Energy + SunPower Production)

In the following tables, we compared the model data (labeled “GE”) with actual data (labeled “PG&E”).

2BR Units	GE (kWh)	PG&E (kWh)
Unit 2BD A	2,994	1,104
Unit 2BD B	2,994	2,030
Unit 2BD C	2,354	1,610
Unit 2BD D	1,979	1,581
Unit 2BD E	1,979	1,099
Unit 2BD F	2,381	1,007
Unit 2BD G	2,002	1,994
Unit 2BD H	2,002	688
Unit 2BD I	2,354	910
Unit 2BD J	2,354	1,273
Unit 2BD K	652	86
Unit 2BD L	1,908	147
Total	**25,951**	**13,529**

3BR Units	GE (kWh)	PG&E (kWh)
Unit 3BD A	3,546	3,461
Unit 3BD B	3,546	3,413
Unit 3BD C	3,546	3,192
Unit 3BD D	2,695	3,460
Unit 3BD E	3,127	3,397
Unit 3BD F	3,127	2,875
Unit 3BD G	3,127	2,164
Unit 3BD H	2,695	2,605
Unit 3BD I	1,981	1,695
Unit 3BD J	2,800	1,601
Unit 3BD K	3,546	1,941
Total	**33,738**	**29,803**

4BR Units	GE (kWh)	PG&E (kWh)
Unit 4BD A	4,195	3,501
Unit 4BD B	4,195	2,253
Unit 4BD C	4,195	5,697
Unit 4BD D	3,700	2,566
Unit 4BD E	3,190	1,643
Unit 4BD F	3,700	3,185
Unit 4BD G	4,195	3,564
Unit 4BD H	3,190	1,715
Unit 4BD I	4,195	4,052
Unit 4BD J	4,195	2,973
Total	**38,949**	**31,149**

Table 10: Comparison of GE Model Consumption Results with Actual Historical Consumption Data

We can make the following observations:

- Actual historical data show a very wide variation, likely due to the evolution in tenancy, occupancy, etc., during the study period, as well as the wide range of student living and consumption patterns.
- GE model data comes close to actual historical data for a few units.
- GE model projections are on the "conservative" side, i.e., they are projecting higher energy consumption compared to actual historical values.
- Units that demonstrate extreme variation from our model may reflect specific occupancy patterns or the presence of end use loads that differ significantly from our model assumptions.

There are various ways to improve the model further. Options are:

- Keep as is (be conservative).
- Scale monthly data patterns to come close to actual historical total values.
- To show variability, add stochastic/probabilistic multipliers for each unit based on the statistical variation seen in PG&E data.
- Refine occupancy model to match aggregate data.

2.5 Model Summary Results

Under our simplifying assumptions, covering the following:

- Occupancy Type
- Seasonality Pattern
- Scaling of Energy Use by Bedroom Numbers

- 10% Miscellaneous Plug Load
- Lighting: 1.2 W/SF + 125 W
- Scaled Cooling Energy Requirement: 1.40 kWh/SF-Year
- Scaled Heating Energy Requirement: 3.24 kWh/SF-Year

Our current model representation of UC Davis West Village's overall performance is as follows:

- Annual Solar PV Electricity Production: 9,271 MWh
- Annual Electricity Consumption: 12,042MWh
- Consumption to Production Ratio: 125%

These results are "demonstrative" based on our preliminary underlying assumptions, and we expect them to be very sensitive to changes in the main drivers such as appliance, lighting, cooling, and heating, assumptions. Other assumptions that can have potentially significant impacts are Appliance Multiplier and Occupancy Pattern assumptions.

Results have been summarized in the following tables.

Individual Unit Type	Area (SF)	Production (kWh)	Consumption (kWh)	C/P	P/A (kWh/SF)	C/A (kWh/SF)
Phase-1-Ramble-2	16,797	64,716	140,117	217%	3.85	8.34
Phase-1-Ramble-3	89,762	375,636	723,122	193%	4.18	8.06
Phase-1-Ramble-4	136,488	565,053	1,059,303	187%	4.14	7.76
Phase-1-Ramble-Common	N/A	454,642	0	0%	N/A	N/A
Phase-1-Viridian-1	44,442	212,486	348,219	164%	4.78	7.84
Phase-1-Viridian-2	71,802	257,025	520,455	202%	3.58	7.25
Phase-1-Viridian-3	4,113	13,814	29,232	212%	3.36	7.11
Phase-1-Viridian-Common	N/A	305,885	0	0%	N/A	N/A
Phase-2-Ramble-2	39,192	242,094	323,111	133%	6.18	8.24
Phase-2-Ramble-3	62,143	383,865	495,766	129%	6.18	7.98
Phase-2-Ramble-4	136,488	843,105	1,050,431	125%	6.18	7.70
Phase-3-Solstice-2	38,588	219,351	294,892	134%	5.68	7.64
Phase-3-Solstice-3	42,575	242,020	312,354	129%	5.68	7.34
Phase-3-Solstice-4	114,290	649,681	812,920	125%	5.68	7.11
Faculty-Staff-Housing-1	83,018	512,813	835,913	163%	6.18	10.07
Faculty-Staff-Housing-4	591,613	3,654,473	4,037,596	110%	6.18	6.82
Recreation-Viridian-Club	16,901	168,424	422,087	251%	9.97	24.97
Recreation-Viridian-Gas	N/A	41,647	61,198	147%	N/A	N/A
Mixed-Use-Retail	44,028	401,427	563,870	140%	9.12	12.81
Other-Use-EV Fleet	N/A	0	11,280	N/A	N/A	N/A
Total	**1,532,239**	**9,608,156**	**12,041,867**	**125%**	**6.27**	**7.86**

Table 11: Summary Results by Individual Unit Category

Aggregate Unit Type	Area (SF)	Production (kWh)	Consumption (kWh)	C/P	P/A (kWh/SF)	C/A (kWh/SF)
Phase-1-Ramble	243,047	1,460,047	1,922,542	132%	6.01	7.91
Phase-1-Viridian	120,357	789,210	897,906	114%	6.56	7.46
Phase-2-Ramble	237,823	1,469,063	1,869,308	127%	6.18	7.86
Phase-3-Solstice	195,452	1,111,052	1,420,166	128%	5.68	7.27
Faculty Staff Housing	674,631	4,167,286	4,873,509	117%	6.18	7.22
Recreation	16,901	210,070	483,285	230%	12.43	28.60
Mixed-Use	44,028	401,427	563,870	140%	9.12	12.81
EV Fleet	N/A	0	11,280	N/A	N/A	N/A
Total	**1,532,239**	**9,608,156**	**12,041,867**	**125%**	**6.27**	**7.86**

Table 12: Summary Results by Aggregate Unit Category

In the table of summary results by aggregate unit category it can be observed that on a per unit area basis, the projected PV generation per area (P/A) shows significant variation across unit types. Variations in the Production/Area values by unit type point at the potential for additional PV installations.

It should also be noted that the zero values are not literally so, and in the above tables indicate unavailable information.

2.6 Conclusions of Subtask 1

Due to the limitations of the data available at the time of our Study and the challenges encountered in preparation of the baseline energy model,our model results provide only an interim snapshot of the current and expected energy performance at UC Davis West Village. However, several directional observations are possible. We believe, based on the information available and the conservative nature of our modeling, that it is likely that:

- The multi-tenant units are performing slightly above production of the installed PV, with some variation by unit type. The Viridian units appear to have the best performance (C/P close to 1), while the Ramble and Solstice units are farther "above ZNE" and may require some additional "tightening" of performance to achieve energy balance.
- The Rec and Lease center and swimming pool area (the "Club" and "Gas" accounts), as well as the MU spaces appear to have a greater excess of consumption over production.
- Our model confirms that the Faculty Staff Housing does appear to be well designed for consumption to match production, with small variations by floor plan and solar size. However, the studio annex units, which are an optional addition for some home owners, may have an additional challenge meeting this goal, due to a lack of roof space to support solar installation.

- Finally, above and beyond the data limitations in our study, there remains uncertainty in the evolution of future loads which have not been estimated adequately, notably the EV charging and energy-intensive operations associated with the Western Cooling Efficiency Center.

UC Davis is planning to construct a Renewable Energy Anaerobic Digester that is expected to produce approximately 4 million kWh of electricity per year. The contribution of this renewable energy resource has not been considered towards the ZNE goal in our model.

Subtask 2 presented in Section 3 below outlines a comprehensive program for on-going tracking of energy performance and develops recommendations for achieving ZNE where current performance may not be meeting the objective.

3 Subtask 2

3.1 Subtask 2 Introduction

Based on the analysis and baseline model created in Subtask 1, Subtask 2 seeks to answer the second key question of our study:

- Where the ZNE goal is not being achieved, what levers are available to adjust energy performance within UC Davis West Village?

The following sections present the functional specification and recommendations for implementation of a monitoring and control systems architecture for UC Davis West Village, including a cost-benefit framework for improving energy management, and recommendations for both specific technology options and other program design elements.

In section 3.2, we present a functional specification for the overall system architecture that will allow on-going energy performance management at UC Davis West Village. We envision a centralized "Master Energy Manager" – a performance tracking system, running on ordinary desktop software and updated daily with data from currently available or soon to be available sources, along with associated communications to the residents (and their intelligent end-use devices) to effectuate demand controls when necessary to adjust performance. This system would ideally be updated and operated by on-site personnel within UC Davis West Village (i.e. either UC Davis staff or a WVCP Partners' facility manager already responsible for building operations).

In Section 3.3, we evaluate a range of commercially available technology options and present recommendations for each building unit type, based on the directional results of Subtask 1 presented in Section 2.6 above.

Section 3.4 presents a cost-benefit example, showing the economics of alternative technology options for energy management and control, using assumptions of DR impacts developed from the available literature on utility pilot programs.

Finally, Section 3.5 offers recommendations with regard to non-technical program design features. This includes a discussion of the regulatory barriers to implementation of price-based incentives for demand management in the multi-tenant units ("the Rule 18 issue"). We also provide some comments on non-technical aspects of program design, such as the user-friendliness and usability of different energy management solutions within the specific context of UC Davis West Village.

3.2 Functional Specification

During development of the UC Davis West Village Energy Initiative, UC Davis and WVCP agreed upon broad parameters for achieving the Zero Net Energy master plan. It was agreed that UC Davis West Village properties would be made attractive, efficient, livable, and affordable – no more expensive than comparable properties elsewhere in the community. This meant that many potential design alternatives that could achieve higher energy performance at some increase in cost were rejected.

In assessing opportunities for improving energy performance from baseline, we have attempted to adhere to the Partnership's objectives, and to specify a design for energy monitoring and control that will allow on-going energy performance tracking and, where needed, performance improvement, at the least possible incremental cost. For example, investments in upgrading capital equipment – such as changes to building envelope, or the addition of smart appliances, or more efficient HVAC systems – were ruled out on the basis of cost.

For purposes of this study, we have concentrated exclusively on energy management and control systems. We believe these technologies represent the likeliest "low hanging fruit" of investment that can be made within the existing design to most easily modify energy performance at the lowest cost. It is our contention that energy monitoring and control is the missing piece of the puzzle at UC Davis West Village that can help translate *good design* into *good practice*, by translating the concept of Zero Net Energy into daily performance tracking and commands that can be issued to compel specific control actions, when needed. As shown by the cost-benefit examples in Section 3.4 below, the investment case for this level of incremental control is likely to be quite compelling.

3.2.1 Master Energy Manager System

The core of our proposed architecture is what we are calling a Master Energy Manager (MEM), a centralized energy performance monitoring and control system that would provide the following functionality:

- Continuous tracking of production and consumption of all existing (built and occupied) properties within UC Davis West Village, through automated daily download from available sources of interval data (SunPower and PG&E);
- Periodically updated modeling of future/under construction properties, including both planned generation and loads, to reflect any new information and changes in anticipated design/occupancy/tenancy and end use;
- Calculation of net energy performance in a simple desktop model, building on the baseline spreadsheet model developed in Subtask 1; and

- Broadcast messaging capability to issue event signals to participating residents and/or intelligent devices, such as IP-addressable programmable/communicating thermostats capable of directly receiving and responding to such signals with appropriate, pre-programmed control action.

3.2.2 Performance tracking

The first and most important feature of a centralized MEM will be to provide a consistent mechanism for tracking energy performance, through daily automated download of interval data for both production and consumption of electric energy in all UC Davis West Village Units.

3.2.2.1 SunPower interval production data

As noted in Section 2 above, the SunPower user interface provides download access for an authenticated user to view kWh production data from the solar inverter installed on each unit. Data are available on a rolling one week basis, but are neither validated nor archived by SunPower. The MEM should include a script to automate download and archiving of the SunPower interval data for each unit, ideally on a daily basis, in order to populate the production side of the desktop model.

3.2.2.2 Interval consumption data

At the time of this study, two options were available for providing future, on-going access to interval consumption data for the existing units at UC Davis West Village. First, SunPower provides non-revenue grade monitoring of consumption at each unit via a Current Transformer clamp at the unit junction box. Access to this data is made available on a one week rolling basis, similar to the interval production data.

Unfortunately, as discussed in Section 2.2.3 above, during the course of the baseline modeling effort in Subtask 1, the GE team uncovered anomalies in this data that made it unusable. GE brought these issues to the attention of SunPower and SunPower confirmed an error in its user interface that was corrupting reporting of the consumption data. SunPower reports that this problem is now fixed, however, historical data have not been archived. Assuming the data can be validated going forward, we believe that the SunPower consumption data could be utilized to support the MEM desktop model.

Independently, another possibility is automating upload of interval consumption data directly from the PG&E smart meters at UC Davis West Village via the “Green Button” program. Green Button is a national initiative, sponsored by the federal government (under the White House Office of Science and Technology Policy) with voluntary participation by many U.S. utilities, including all three of the California Investor Owned Utilities. The Green Button interface provides a standardized web-based format for export of meter data history

to customers and their authorized representatives, allowing wider use of the data in third party energy management software applications.

For interval metered customers, such as all PG&E Smart Meter customers, Green Button should provide interval data within 24-36 hours of usage. These data have been through basic validation checks within PG&E's Meter Data Management System and are therefore likely to be more consistent with the final "revenue grade" data used to generate the monthly PG&E bill[21]. If WVCP is able to secure access to the Green Button data for UC Davis West Village accounts, this would represent – in our opinion -- the best, most reliable source of interval consumption input to the MEM.

3.2.3 MEM Desktop Model

The objective of the MEM is to continuously gather in one place all the data necessary to track performance against the ZNE goal. Based on the availability of interval production and consumption data, a simple desktop model should be able to track performance for the UC Davis West Village community on a continuous basis. This model can be structured based on the baseline energy model developed in Subtask 1 to represent each unit type – with actual data for existing units and simulated performance of to-be-built units – in order to provide a comprehensive view of energy performance. Such a model can readily be set up to detect and predict trends, such as expected deviations from desired levels of energy performance.

In section 3.3 below, we lay out recommendations for different levels of demand side technology that could be used to "tighten" energy performance. In order to implement these recommendations, the MEM desktop model would need to be used in conjunction with a broadcast messaging interface to provide event communications to participating residents via a "blast" text or email option. The following section describes the architecture that would enable the necessary device-level communications.

Below we also consider the implementation of a demand response program that would follow the behavior of PG&E's "Smart Rate" (a voluntary Critical Peak Pricing rate option). In order to effectuate control under this type of program, the MEM desktop model would need to subscribe to automated event information from PG&E (available over the web to participating Smart Rate subscribers) and broadcast event signals to participating residents and intelligent devices within the UC Davis West Village network. In ideal form, the MEM would issue communications to a network of smart thermostats and other intelligent devices present within UC Davis West Village using a standardized DR protocol such as

[21] Additional validation checks are conducted by the utility billing system in calculating the final bill and may result in occasional discrepancies with the Green Button data.

OpenADR or SEP 2.0, over any mix of wireless or powerline communications, in order to effectuate control action.

3.2.4 Communications architecture

As discussed in Section 3.3 below, there are a variety of IP addressable programmable communicating thermostats and other HEM devices on the market with different functionality availability at different price points. These devices all have in common the ability to receive and act on event information and communications related to utility demand response rates, such as PG&E's TOU and Smart Rate options.

Within the UC Davis West Village community, we envision that the MEM desktop model would issue control signal commands and communicate directly with a network of smart devices, such as smart thermostats in the multi-tenant buildings.

Many utility smart grid and demand response pilot programs have experienced difficulty with poor interoperability of equipment from different manufacturers – for example, metering communications that did not work well with in-premise devices. It is GE's understanding that recent advances in the standards landscape, such as the adoption of SEP 2.0 interoperability testing protocols have eliminated much of this risk. SEP 2.0 allows equipment using different physical-layer media – for example, Zigbee™ and HomePlug™ equipment -- to send and receive DR price and event communications with standardized data and message formats.

3.3 Technology Recommendations

There is a considerable literature of reported results from utility demand response pilots. Based on review of this literature and, in particular, recent studies comparing results for different technology and program types[22], we believe that there are three levels of potential investment and associated savings that should be of interest at UC Davis West Village:

- **Consumption Information Delivery**. These "information only" programs provide simple messaging to consumers that warn of high peak load "event days" and offer suggestions to avoid unnecessary electric use, turn back thermostats, and delay scheduled appliance usages (such as dishwasher and laundry loads) until off-peak hours. Such programs are extremely cheap to operate and have a small but

[22] "Rethinking Prices - The changing architecture of demand response in America", By Ahmad Faruqui, Ryan Hledik, and Sanem Sergici, Public Utilities Fortnightly, January 2010. [Permission pending]

noticeable impact on consumption and peak demand, typically in the low single digit percentages of peak demand reduction (2-5%).

- **TOU with programmable communicating thermostat**. Time-of-Use (TOU) rate schedules charge differential prices by pre-determined seasonal/time-of-day blocks – more in summer peak hours (for summer-peaking systems), less in winter and off-peak night time hours. Programs that tie installation and programming of thermostats to a TOU price incentive can result in more significant reductions in energy and peak demand, often on the order of 10%.
- **CPP with programmable communicating thermostat**. Critical Peak Pricing (CPP) overlays on the basic TOU structure an event-driven higher rate that can be invoked by the utility up to a certain number of times per year. PG&E's voluntary Smart Rate option is an example of a CPP. IP addressable programmable communicating thermostats (PCTs) are now available from a number of manufacturers that can receive and respond to dynamic pricing signals in order to provide higher peak savings on an event basis – often as much as 20% or more.

All units in the UC Davis West Village multi-tenant buildings come equipped with programmable thermostats, however, these are basic devices that are not communications-enabled and cannot be remotely accessed by the envisioned MEM to provide dynamic control. Due to the limitations of the user interface, most consumers find such devices difficult to program and maintain. Typically, they are set once when installed and only occasionally, if ever, reprogrammed by the tenants.

In order to achieve savings above the "Information Only" level, we examine the cost-benefit argument for replacement and upgrade of the current thermostat with an IP-addressable PCT in Section 3.4 below.

There are a number of technology vendors and options for PCTs that can support varying levels of control. Simple devices in the ~$100 range are available from companies such as EnergyBuddy, EnviR, and Battic. Higher end home energy management kits are also available that include such features as more intuitive full color touch screen displays and Zigbee™ (wireless) plug adapters for on/off control of additional simple plug devices in the home. Kits of this sort run in the ~$250 range and are available from NEST, EverSense, EcoBee, and EnergyHub, among others.

Finally, there is an emerging category of "cloud based" software-as-a-service vendors, such as EcoFactor, which offer subscription-based services to remotely control and optimize thermostat settings. Pricing was not available for EcoFactor.

For the Faculty Staff housing at UC Davis West Village, no thermostats have yet been installed (or specified to our knowledge), and there does not appear to be any restriction that would prevent the community from requiring or encouraging PCT installation and PG&E

Smart Rate participation for home owners (who will be customers-of-record for their own PG&E accounts) as part of the community covenants or HOA rules.

In investigating options for the Rec and Lease Center and Mixed Use Retail buildings, we were not able to provide specific suggestions. However, a number of vendors offer advanced building energy management and control solutions that may offer significant savings. These include Scientific Conservation, Inc. (SCI), 8760, and BuildingIQ.

Finally, for the pool pumping load, we identified a recent report of over 40% energy savings at two of UC Berkeley's outdoor campus pools using smart pumping controls[23]. Although GE is not familiar with the vendors in this space, this appears to be a direction well worth investigating further, as it could significantly contribute to better overall energy balance.

3.4 Cost-Benefit Examples

In this section we analyze the dollar value of several possible technology upgrades. Using the data from the baseline model developed in Subtask 1, we present a cost-benefit analysis per unit. In particular, the analysis is shown for Ramble Phase 1 apartments for which the data set is most complete. We assume impacts of technology based on results from the available literature on utility pilot programs.

We consider three scenarios that differ in technology and the type of energy management program applied:

- Consumption Information Delivery (CID): The information about consumed energy is communicated to residents, but there are no control actions.
- Time-Of-Use program (TOU): Consumed energy is controlled through a fixed schedule known to residents.
- Critical Peak Pricing program (CPP): Consumed energy is controlled through a dynamic schedule.

We present details of each program in sections 3.4.1., 3.4.2, and 3.4.3 respectively.

All of the individual apartments in the UC Davis West Village community are expected to be on the E-6 Rate Schedule, which is PG&E's Residential Time-of-Use Schedule. According to this schedule the consumed energy is billed based on the time of day. In particular, there are different rates for "on-peak", "partial-peak" and "off-peak" periods. In addition, these periods are different during summer and winter seasons. Following table defines the TOU periods for PG&E's E-6 schedule.

[23] http://recsports.berkeley.edu/new-energy-saving-pool-pumps/

Summer (May-October)		
Peak:	1:00 pm to 7:00 pm	Monday through Friday
Partial-Peak:	10:00 am to 1:00 pm	Monday through Friday
	7:00 pm to 9:00 pm	Monday through Friday
	5:00 pm to 8:00 pm	Saturday and Sunday
Off-Peak:	All Other Hours	Including Holidays
Winter (November-April)		
Partial Peak:	5:00 pm to 8:00 pm	Monday through Friday
Off-Peak:	All Other Hours	Including Holidays

Table 13: E-6 Time-of-Use Periods

As explained in section 2.2, the hourly consumption data from SunPower turned out to be unreliable and was not used in the scope of this project. In order to perform the analysis of benefits, we needed a different way to estimate residential hourly usage.

PG&E maintains class average load profiles based on a representative sample of customers in each rate class that are updated "dynamically". These samples have been maintained continuously since 2000, when Dynamic Load Profiling was created to support the needs for retail settlement in the deregulated market. The data continue to be published and updated daily and historical data are posted to the web at:

http://www.pge.com/nots/rates/006f1c4_class_load_prof.shtml.

We used the historical data for PG&E's E-1 (residential general service) rate to compute percentages of total energy consumed in each of the five TOU periods as shown in Table 16. The numbers are reasonably similar across the years, so in our analysis below we used the average values. For each of the three cases we combined this data with the baseline model consumption and production data to determine the appropriate PG&E rates and compute the difference in energy bill before and after the energy management program is applied.

Year	Summer Peak	Summer Partial-Peak	Summer Off-Peak	Winter Partial-Peak	Winter Off-Peak
2000	22.0913	22.1952	55.7135	12.5457	87.4543
2001	21.7761	21.7727	56.4512	12.4583	87.5417
2002	21.6373	21.837	56.5257	12.3042	87.6958
2003	22.0491	21.9547	55.9963	12.2033	87.7967
2004	21.8544	21.7492	56.3964	12.3614	87.6386
2005	21.4899	21.7639	56.7461	12.0596	87.9404
2006	22.0804	21.9523	55.9673	11.8976	88.1024
2007	22.0739	21.7571	56.1691	11.7809	88.2191
2008	22.2361	21.8649	55.899	11.8403	88.1597
2009	22.0543	21.8407	56.105	11.8044	88.1956
2010	21.3257	21.7668	56.9075	11.8563	88.1437
2011	21.9846	21.6607	56.3547	11.4129	88.5871
2012	22.2407	21.8403	55.919	11.2113	88.7887
Average	**21.9188**	**21.844**	**56.2371**	**11.9918**	**88.0082**

Table 14: Averaged percentages of energy consumed in different TOU periods

3.4.1 Consumption Information Delivery

In this program the information on energy usage and event conditions is periodically sent to residents, but there is no automatic control of end-use devices. Participating residents are assumed to manually control thermostats and other appliances in response to information.

Studies [Fischer 2008], [Faruqui 2009] and [ACEEE 2010][24] have argued that programs based only on energy consumption feedback can result in savings ranging from 2-6 percent. Note that the communicated information is not broken into individual TOU periods. Thus, in our analysis we assumed that the energy reduction is proportional in each of the TOU periods. With this assumption and considering the appropriate PG&E rates, the average benefit per year per unit can be computed for each apartment complex of the community. Figure 7 shows how the benefit depends on the percentage of energy saved for the Ramble Phase 1

[24] Fischer C. 2008. "Feedback on Household Electricity Consumption: A Tool for Saving Energy?" Energy Efficiency 1(1):79-104. DOI: 10.1007/s12053-008-9009-7. Available at

www.springerlink.com/index/276m42024x61wh1h.pdf.

American Council for an Energy Efficient Economy (ACEEE). 2010. Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Saving Opportunities. Available at http://www.aceee.org/research-report/e105

Faruqui A, S Sergici, and A Sharif. 2009. "The Impact of Informational Feedback on Energy

Consumption – A Survey of the Experimental Evidence." Energy.

complex. For instance, for the energy reduction of 2% we get $27.57 value savings per year per unit.

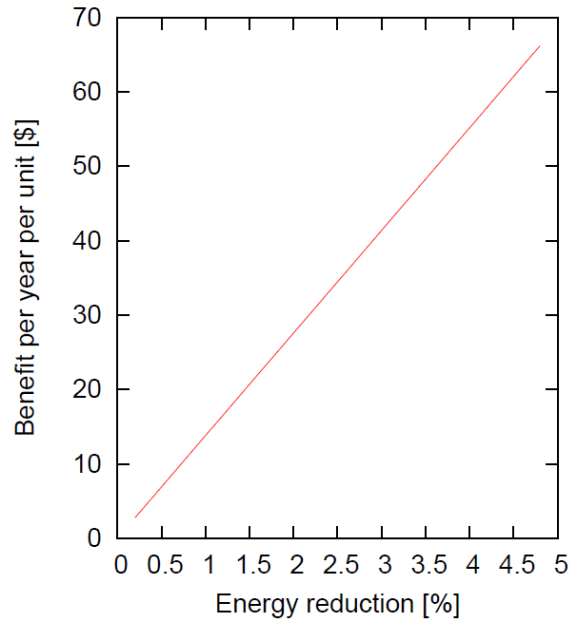

Figure 7: Benefit of the CID program per year per unit [$]

In simplest scenarios, this program can be implemented with almost no additional investment in technology. The MEM described in Section 3.2 above would send daily consumption information and event messages through email or text messages.

A more sophisticated option would be providing the residents with devices that measure consumption of individual appliances. For example, smart plugs, such as *Kill-A-Watt* cost around $20. More sophisticated solutions measure and display total consumption of a unit, based on multiple smart end-point devices, typically sold as a kit. A typical Home Energy Management system consists of a power meter, a Wi-Fi transmitter and a display. Examples of this technology that cost around $100 include *EnergyBuddy, EnviR and Battic.*

3.4.2 Time-Of-Use Program

In this program, in addition to feedback on usage, the HVAC system is controlled through programmable communicating thermostats (PCT). This is performed by a centralized command from the MEM. However, residents are allowed to override the command at any time. The control takes into account TOU periods trying to shift usage to a lower cost period. Thus, the benefit comes both from energy savings and reduction of loads in the peak period. Previous pilot studies of this type have shown that around 5% of energy reductions [Ontario

2007][25] together with about 10% of peak load reduction [Edison 2008] can be achieved with such a program.

By manipulating the distribution of energy consumed in different TOU periods with the assumed values of energy and peak load reduction percentages one can estimate average dollar value of benefits for this program. Figure 8 shows this for an average Ramble Phase 1 apartment for a range of energy and peak load reductions. For instance, with the expected 5% energy and 10% peak load reductions the estimated benefit would be $76.54 per year per unit.

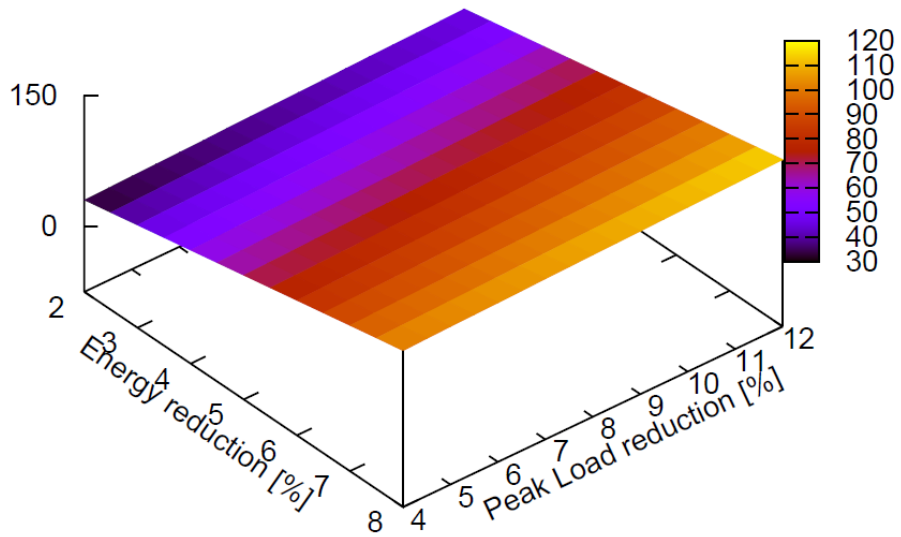

Figure 8: Benefit of the TOU program per year per unit [$]

Programmable communicating thermostats (PCT) and other smart appliances can communicate wirelessly through the Internet or via a home automation technology. The costs of wirelessly controlled light and fan controllers are in the $50-100 range (e.g. *Insteon*). The simplest PCTs start at around $100. More advanced thermostats, which can be adjusted via Internet-capable smart phones to allow residents to remotely adjust the temperature settings in their units, cost above $200 (e.g. *NEST, EverSense*).

[25] Ontario Energy Board Smart Price Pilot, 2007, available at:

http://www.oeb.gov.on.ca/documents/cases/EB-2004-0205/smartpricepilot/OSPP%20Final%20Report%20-%20Final070726.pdf

Edison Electric Institute 2008 Study, available at:

http://www.smartgridinformation.info/pdf/2399_doc_1.pdf

3.4.3 Critical Peak Pricing Program

In the CPP program, the time-of-use rates are in effect most of the time, except for certain peak consumption days, when prices are considerably higher. For instance, in PG&E's SmartRate Plan, from 2 p.m. to 7 p.m. on so called SmartDays, there is surcharge of $0.6 per consumed kWh on electricity. No more than 15 SmartDays with this critical peak rate are called each summer season. Due to such a high surcharge residents shift considerably more energy usage out of this critical peak period. In this program the Property Manager Office would again control PCT's and potentially other appliances, but this time on a more dynamic schedule. The residents would still have an option to override these settings.

Various pilot projects have shown that CPP programs can yield substantial critical peak load reductions. For instance, according to the review in [Edison 2008] all cited CPP studies reported critical peak load reductions above 10%, most often around 20%. Figure 9 shows average benefits of an apartment in Ramble Phase 1 complex for a range of critical peak and peak load reductions with the assumed value of 8% for the total energy reductions. For instance, with the expected 20% critical peak and 10% peak load reductions the estimated benefit would be $101.7 per year per unit.

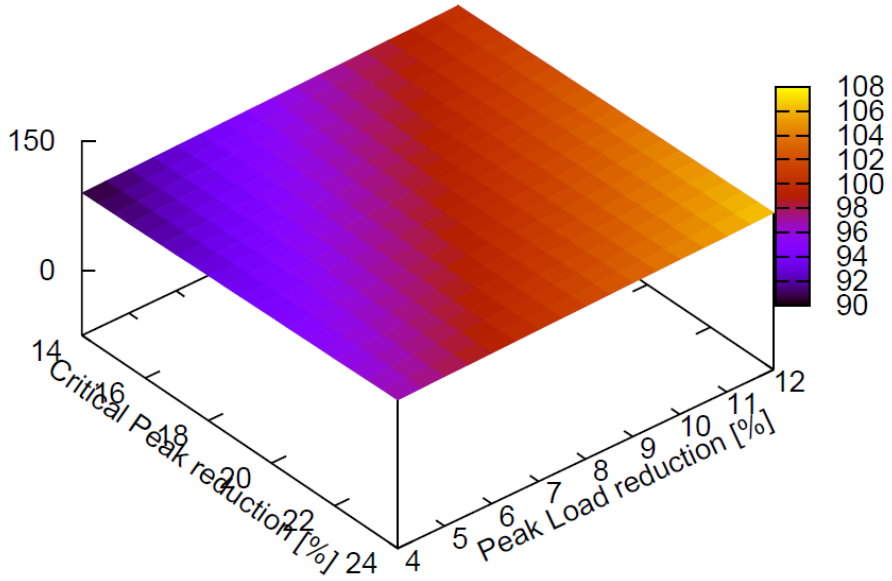

Figure 9: Benefit of the CPP program per year per unit [$] (for energy reduction of 8%)

The technology solutions used for this program would be similar to those listed for the TOU program at the end of section 3.4.2 with the exception that software for dynamic control would be more sophisticated. Moreover, providers such as *Ecofactor* have recently started to partner with utilities to offer subscription based services that collect usage and

temperature data and control thermostat settings much more frequently and using big-data analytics.

3.5 Program Recommendations

3.5.1 Rule 18

PG&E Electric Rule 18[26] governs "Supply to Separate Premises and Submetering of Electric Energy" and specifies conditions for electric service in multi-tenant buildings. The original intent of Rule 18 was to prevent a landlord or property manager from intervening in the metering relationship between PG&E and its customer, by, for example, altering the meter read or charging a premium above PG&E rates for service to the ultimate customer. Rule 18 also prevents such fraud as charging one customer for another's usage or serving a non-residential customer under a residential rate.

WVCP has been informed by PG&E that under Rule 18, it may not pass along TOU or dynamic pricing schedules to the tenants at UC Davis West Village. We do not find this restriction anywhere in the clear language of Rule 18 covering Residential Service[27], but understand that interpretation of the tariff rules can be an art.

Our understanding of the situation in the multi-tenant buildings is that they are individually metered (not master-metered) residential accounts for which WVCP is designated as the billing agent and pays the bills directly to PG&E. Costs of utility service are then passed along to the tenants through fees included in their rent. Since the tenant does not directly pay the utility bill, they do not see any incentive to conserve or to move usage to cheaper, off-peak periods. WVCP has established a system of penalties if a tenant exceeds a certain maximum threshold of kWh in a month.

One option, if allowed without violating Rule 18, would be to establish a similar system of price penalties if a tenant does not follow a prescribed peak demand reduction – for

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[26] http://www.pge.com/tariffs/tm2/pdf/ELEC_RULES_18.pdf

[27] The following provision for master-metered Non-Residential Service, under 18.C.2.b, may be related:

> "2) Where a master-meter customer installs, owns, and maintains electric submeters on its existing building's distribution system for *cost allocation of dynamic pricing and/or conservation incentive purposes* the cost of electricity allocated to the commercial building tenants will be billed at the same rate as the master meter billed by PG&E under the CPUC approved rate schedule servicing the master meter." [italics added]

example, by ignoring an event signal or overriding the settings on a programmable thermostat.

In the event Rule 18 does indeed prevent direct price-based incentives and penalties, there may be alternative options for motivating demand responsive behavior in the multi-tenant buildings:

- Option 1: Non-price incentives. By using prize awards for participation, such as T-shirts or "Aggie bucks", the WV Partnership could stimulate social competition among tenants to encourage greater program participation.
- Option 2: Centralized (rather than distributed) control of devices. Under this option, the MEM would need to be able to directly communicate with and control thermostats and other HEM devices within UC Davis West Village. Individual tenants could still retain override capability to temporarily reset their unit thermostats to provide higher comfort, but the device could be programmed to automatically restore to its default settings after a certain period of time or whenever new instructions are issued from the MEM (similar systems are found in many hotels). In principle, this should not violate Rule 18 authority, since the tenant would be ceding control of its end-use equipment, which, though perhaps somewhat invasive, is not a utility asset and therefore non-CPUC jurisdictional.

Time and scope did not permit us to investigate these options further.

3.5.2 Other Program Considerations

Students are not typical residential electric consumers and any on-going program of energy management and control in UC Davis West Village should be sensitive to the unique demographics of the student population in the multi-tenant units, if it is to be successful.

Students vary significantly from the general adult population in terms of:

- Lifestyle pattern and daily schedule
- Use of major appliances (less laundry and cooking; more computers and gaming consoles)
- Low disposable income
- High acceptance of new technology

One recent technology that may prove well-suited to student lifestyles is the Allure Energy EverSense thermostat and GPS based smart phone app announced at the 2013 Consumer

Electronics Show[28]. This system links to a PCT to provide location-based awareness, such that if a consumer goes more than a certain distance (e.g. three miles) from home, the app automatically puts the thermostat into energy savings mode. Since Davis students lead less predictable schedules than most consumers (while rarely leaving home without their smart phones), this feature would seem a good fit.

3.5.3 Policy Recommendations

According to the CPUC, "The goal of the California Solar Initiative (CSI) Research, Development, and Deployment (RD&D) plan is to help build a sustainable and self-supporting industry for customer-sited solar in California." In the course of GE's work on Task 2, we uncovered several flaws or gaps in the current policy and regulatory design that affect the ability of West Village to fully realize and implement the vision for zero net energy communities as a viable keystone of California's solar growth. The following observations and recommendations are therefore directed at the policy audience as funders of the CSI RD&D program, and go beyond the specific opportunities for UC Davis or the West Village Energy Partnership.

- **Defining ZNE on an annual energy basis as a performance metric does not incent the most economically efficient combination of distributed energy resources.** A key difference between electricity and other energy commodities is the highly time-sensitive value of electric energy on the grid, which can vary by an order of magnitude or more over the course of a single day. West Village, as a ZNE community, may or may not maximize the benefits it provides to the larger California electric grid, depending on the timing of energy exports and imports needed to maintain net energy balance over the course of the year. To the extent that West Village residents and businesses produce net energy (generation greater than consumption) at times that align with high value peak hours and consume net energy (consumption greater than generation) primarily during off-peak hours and seasons of the year, West Village should be rewarded for this value. Conversely, if West Village is achieving ZNE by producing net energy off-peak and consuming net energy on peak, it should be penalized. The current annual calculation does not differentiate between peak and off-peak resources, and therefore, as a design criterion, does not incent investment in the societally efficient mix of resources.

  As an example, solar PV, while generally coincident with air conditioning loads that drive system peaks in California will nevertheless tend to contribute more energy during the mid-day period on hot summer days (when the sun angle is optimal for PV

[28] http://www.greentechmedia.com/articles/read/allures-eversense-says-its-one-better-than-a-learning-thermostat

generation) and too little energy during evening shoulder hours, which correspond better with the consumption peak. If the desired goal of ZNE is to minimize the net impact of new load on the grid, the current emphasis on PV may not be helpful. Especially in a residential setting, and with a student population that incurs peak demand well into the nighttime hours, it is likely that the annual ZNE goal is not the most accurate measure of system costs and benefits. GE believes that a modified metric that takes better account of the time value of electricity (driven by the capacity costs of serving peak demand) would provide a more accurate overall basis for evaluating energy performance at West Village, as well as a stronger incentive for alternative DER investment. These alternatives might include not only more advanced demand controls, but potentially economic investments in battery energy storage, smart EV charging systems, and other renewable generation alternatives that are not currently in scope at West Village.

Fundamentally, zero is just a number. Whether zero net energy is the "right" number from a policy perspective – that is, whether the goal of net energy balance over the course of a year results in the mix of resources that best meets the underlying policy objectives (such as stabilization of greenhouse gas emissions and efficient capital investment) at lowest cost, depends on the cost of balancing supply and demand with local distributed resources and controls, as compared to the cost of alternatives on the larger grid, such as utility scale renewables, combined with flexible conventional generation and/or storage. Without the right success metric in place, it will be difficult to evaluate the merits of projects like West Village in the future and to optimize the efficient use of scarce capital to meet California's ambitious clean energy policy agenda.

- **Multi-family tenants in West Village should be entitled to the same range of demand response tariff options as other residential customers.** During the course of the project, GE was unable to definitively resolve the issue of interpretation of Tariff Rule 18 with regard to the availability of PG&E's demand response rate options for the multi-family units at West Village. As individually metered PG&E customers, the West Village multi-family units should be entitled to participate in the same rate options as other PG&E residential ratepayers and we believe the CPUC would be accommodative of any tariff language waivers or modifications needed to support this objective. We recommend UC Davis and the WVEP continue to work with PG&E and, if necessary, seek regulatory relief to allow DR tariff participation by tenants in the multi-family units.

- **Net Energy Metering customers with smart meters should have separate access to their consumption and production data.** The current AMI architecture being

deployed by PG&E (and to the best of our knowledge, the other California IOUs) provides net energy metered customers with only a net energy kWh read for each metered interval, not separate consumption and production values. This limitation inhibits efforts to measure and achieve local objectives for energy management (such as ZNE) through automated, dynamic control of demand (or eventually storage technologies). While we were able to synthesize a substitute historical data set for benchmarking purposes using the SunPower production data, this data will not be available for all NEM customers, nor can it be easily compared and reconciled with PG&E billing data (due to differences in the read cycle, for example). Finally, data from local pulse metering of consumption may not be of the same quality or revenue-level accuracy as utility metering, which is subject to numerous CPUC regulations and industry standards (i.e., the ANSI c12 series). While cognizant of the costs of changes in the existing deployments, GE recommends that California policy makers consider evolving the requirements for AMI data collection to better accommodate the needs of NEM customers to make informed energy choices, with transparency to both the production and consumption side of the ledger.

4 Summary of Recommendations

In Subtask 1, GE developed a baseline model of energy performance at UC Davis West Village, based on the best available information. Given the limitations and challenges inherent in this effort, we were unable to make a definitive assessment of current energy performance, but believe our results support several directional observations. We believe, based on the information available and the conservative nature of our modeling, that it is likely that:

- The multi-tenant units are performing slightly above production of installed PV, with some variation by unit type. The Viridian units appear to have the best performance (C/P close to 1), while the Ramble and Solstice units are farther "above ZNE" and may require some additional "tightening" of performance to achieve energy balance.
- The Rec and Lease center and swimming pool area (the "Club" and "Gas" accounts), as well as the MU spaces appear to have a greater excess of consumption over PV production.
- Our model confirms that the Faculty Staff housing do appear to be well designed for consumption to match production, with small variations by floor plan and solar size. However, the studio annex units, which are an optional addition for some home owners, may have an additional challenge from PV production alone, due to a lack of roof space to support solar installation.
- Finally, above and beyond the data limitations in our study, there remains uncertainty in the evolution of future loads which have not been estimated adequately, notably the EV charging and energy-intensive operations associated with the Western Cooling Efficiency Center.

In Subtask 2, we recommended functional specifications and a set of monitoring and control options to address tightening the energy performance at UC Davis West Village. The core recommendation is the development of a desktop Master Energy Manager to automate the on-going tracking of performance data (ideally hourly interval production and consumption). The MEM would serve as an on-going "living" version of our baseline model and would manage communications both to residents and directly to addressable devices such as programmable communicating thermostats within UC Davis West Village.

We examined three different levels of potential energy management and control at different levels of technology and cost:

- Consumption Information Delivery
- TOU with PCT
- CPP with PCT

As our cost-benefit examples show, there are attractive simple paybacks of less than three years available with each level of technology. For example, a CID program involving a single $20 plug monitor and achieving energy savings of 2% would pay for itself in less than a year. A TOU program with 5% energy and 10% peak savings saves approximately $75 a year at a cost of $100, for a simple payback of 1.3 years. A CPP program with 8% energy and 10% peak savings, plus an additional 20% critical peak savings, would result in roughly $100 in benefits per year, recovering the initial cost of a $250 advanced HEM system in 2.5 years.

We sketch out two options with regard to addressing program design obstacles, in particular, the apparent constraints of Rule 18 that prevent sharing of dynamic pricing incentives with residents in the multi-tenant units. These are:

- Non-price incentives, such as prize awards; and
- Direct centralized control of thermostats with temporary local override capability.

GE provides several recommendations for improving the policy and regulatory framework for Zero Net Energy communities in California, based on our experience at West Village. We suggest that the ZNE metric – currently a design criteria but proposed as a future building code requirement for new construction in the state -- be modified or elaborated to contain a notion of the varying time value of electric energy. ZNE may be achieved over the course of a year in different ways, some of which will be more beneficial than others. In point of fact, zero is just a number, and the appropriate goal for any given community or building should be to contribute to the overall system sustainability and least-cost energy balance to meet future needs, which will likely depend on a mix both distributed energy resources and cost-effective centralized/utility scale renewable resources.

We also recommend that the CPUC clarify the tariff rules with regard to DR participation by individually metered multi-family units, such as those at West Village. To the extent current rules do not allow all ratepayers on a given rate the same access to the full menu of DR rate options for which they are eligible, waiver or modification to the tariffs should be sought. Finally, we recommend that policy makers consider the needs of Net Energy Metered customers for separate production and consumption data in any future evolution of the AMI data requirements of the California IOUs. Separate production and consumption data are necessary inputs to the cost-effective integration and optimization of demand against local generation resources that is the heart of the ZNE community concept.

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