Application of the Software as a Service Model to the Control of Complex Building Systems

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Abstract

In an effort to create broad access to its optimization software, Lawrence Berkeley National Laboratory (LBNL), in collaboration with the University of California at Davis (UC Davis) and OSISoft, has recently developed a Software as a Service (SaaS) Model for reducing energy costs, cutting peak power demand, and reducing carbon emissions for multipurpose buildings. UC Davis currently collects and stores energy usage data from buildings on its campus.

Researchers at LBNL sought to demonstrate that a SaaS application architecture could be built on top of this data system to optimize the scheduling of electricity and heat delivery in the building. The SaaS interface, known as WebOpt, consists of two major parts: a) the investment & planning and b) the operations module, which builds on the investment & planning module. The operational scheduling and load shifting optimization models within the operations module use data from load prediction and electrical grid emissions models to create an optimal operating schedule for the next week, reducing peak electricity consumption while maintaining quality of energy services. LBNL's application also provides facility managers with suggested energy infrastructure investments for achieving their energy cost and emission goals based on historical data collected with OSISoft's system. This paper describes these models as well as the SaaS architecture employed by LBNL researchers to provide asset scheduling services to UC Davis. The peak demand, emissions, and cost implications of the asset operation schedule and investments suggested by this optimization model are analysed.

Introduction

In order to ensure reliable, low cost, low carbon sources of electricity, large buildings and campuses will increasingly turn from the conventional grid to diverse combinations of distributed energy resources (DER), including distributed generation (DG) equipment, combined heat and power (CHP), and electrical and thermal storage, becoming in essence a microgrid. A microgrid can be defined as cluster of small electricity sources as well as controllable loads. Microgrids can operate safely in a traditional grid-connected mode or perform "intentional islanding" due to economic reasons or in cases of macrogrid outage. Combined with on-site production of heat, microgrids have the capability to emerge as a competitive alternative to the deliver energy to consumers, resulting in economic and environmental benefits. CHP capable distributed energy resources such as internal combustion engines, microturbines or fuel cells coupled with small renewable energy generators such as photovoltaics and wind turbines and grouped in microgrids can introduce a rich set of tools for providing conventional distribution networks (macrogrid) with increased reliability, security of supply, flexibility and power quality (see Microgrids Symposiums 2005-2010).

The successful deployment of microgrids will depend heavily on the economics of DER. Furthermore, if clear economic, environmental, and utility system benefits from such projects are realized, momentum can propel the early adoption of added microgrid capabilities as well as precipitate the regulatory adjustments necessary to allow widespread introduction of these systems (see Stadler 2009).

In this context LBNL researchers have developed the Distributed Energy Resources Customer Adoption Model (DER-CAM), a techno-economic tool capable of finding the optimal combination of DER and its optimal operation schedule for providing a microgrid with its power and heat loads over a typical year (see Siddiqui et al. 2003). DER-CAM minimizes the site's total energy bill and/or CO_2 emissions, normally taking into account the purchase of electricity and natural gas as well as the distributed generators itself. The economical / environmental optimal investment decision, which DER-CAM provides is a complicated problem, relying on a number of factors and constraints such as the microgrid's load profiles, tariffs, and DG options.

DER-CAM has been extensively used by LBNL researchers for two separate purposes: 1) Finding optimal combinations of DG that meet a microgrid's energy loads, attaining economical or environmental objectives and 2) selecting the most efficient operations schedule of a site-specific portfolio of installed technologies, taking into account both costs and CO_2 emissions.

Eventually, this two different approaches lead to the creation of two separate versions of DER-CAM:

1. Investment & planning DER-CAM: this version of DER-CAM finds the optimal investment decisions based on historic observed load profiles and considers also the operation of the selected equipment for a predefined test year, which is based on historic data.
2. Operations DER-CAM: this version of DER-CAM uses the optimal DG equipment delivered from the investment & planning DER-CAM and performs load predictions for the next seven days and optimizes the operational schedule of the pre-defined DER equipment to minimize costs and / or CO_2 emissions.

There has been growing interest in the commercialization of DER-CAM. In that context LBNL developed a partnership with privately-owned OSIsoft LLC, with the intent of setting up a test version of DER-CAM as a web-based "Software as a Service" (SaaS) tool.

OSIsoft had previously developed a system for collecting, managing and analysing critical real-time operating data of any building's facility. University of California at Davis (UC Davis) was selected as a pilot project for the implementation of web-based DER-CAM (WebOpt). This initiative has also led to the development of week-ahead operations DER-CAM. Week-ahead analyses were undertaken for the Segundo Dining Commons building at UC Davis. Load shifting for avoiding consumption in peak periods was also analysed. The week-ahead model uses forecasted data for load prediction. Additionally, LBNL researchers used the investment & planning capabilities of

WebOpt for suggesting DER investments for achieving additional energy cost or CO_2 emissions minimizing objectives.

This paper presents an overview of the latest developments of LBNL's DER-CAM optimization tool, particularly its recent availability as a SaaS tool and explores UC Davis project's findings and results.

Distributed Energy Resources Customer Adoption Model (DER-CAM)

DER-CAM was initially created as an exclusively economic energy model, able to find the cost minimizing combination and operation profile of a set of DER technologies that meet heat and electric loads of a single building or microgrid. Since DER-CAM is an optimization algorithm it solves the technology choice, the appropriate capacity for each selected technology as well as the operational schedule at one stroke[1]. Optimized investment decisions are based on techno-economic criteria, along with site information such as the energy loads, economical details and technology characterization, as schematically illustrated in Figure 1. In general, DER-CAM is also capable of considering the costs and savings of classic efficiency measures as window changes in buildings, though this has not been done in the course of this investigation (Stadler et al. 2009b).

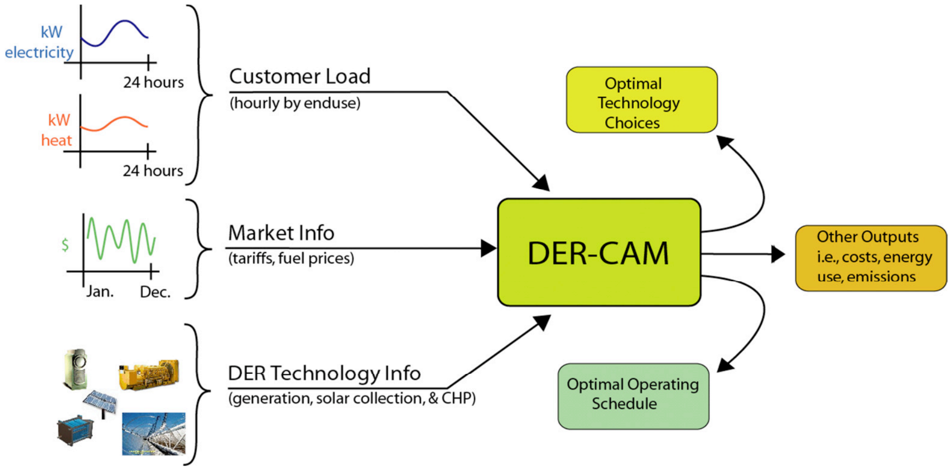

Figure 1. Basic representation of DER-CAM

In detail, key inputs to DER-CAM are:

1. The site's load profiles, disaggregated by fuel type and end use: space heating, hot water (both can be met either by natural gas or recovered heat), gas only (mostly cooking), electricity only (e.g. lighting, miscellaneous electric loads) and cooling (met either by electricity or by heat, via an absorption chiller);
2. The detailed electricity and gas (or other fuels) tariff rates and structure;
3. Detailed DG technology parameters, e.g. capital, operating and maintenance costs of the various available technologies, but also parameters such as the rated power, the electrical efficiency or the heat-to-power ratio of the equipment;
4. Additionally, there are financial factors which are also part of the inputs to DER-CAM and will constrain the investments in DG. These are for instance the maximum allowable payback period of a project or the interest rate on the DG investment.

The following are the main outputs of the investment & planning DER-CAM:

1. The optimal combination of technologies;
2. The optimal capacities of each selected technology;
3. The optimal schedule of operation for a typical year for selected technologies;

Several other outputs result from the DER-CAM analysis, such as energy related costs, detailed emissions, tariff usage information etc. The Sankey diagram in Figure 2 shows the energy flows in a microgrid. DER-CAM solves the system analytically by representing it as a mixed integer linear program written in GAMS® platform.

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[1] More precisely, this is only valid for the investment & planning DER-CAM since the operations DER-CAM just calculates the operational levels for the next seven days, based on load predictions.

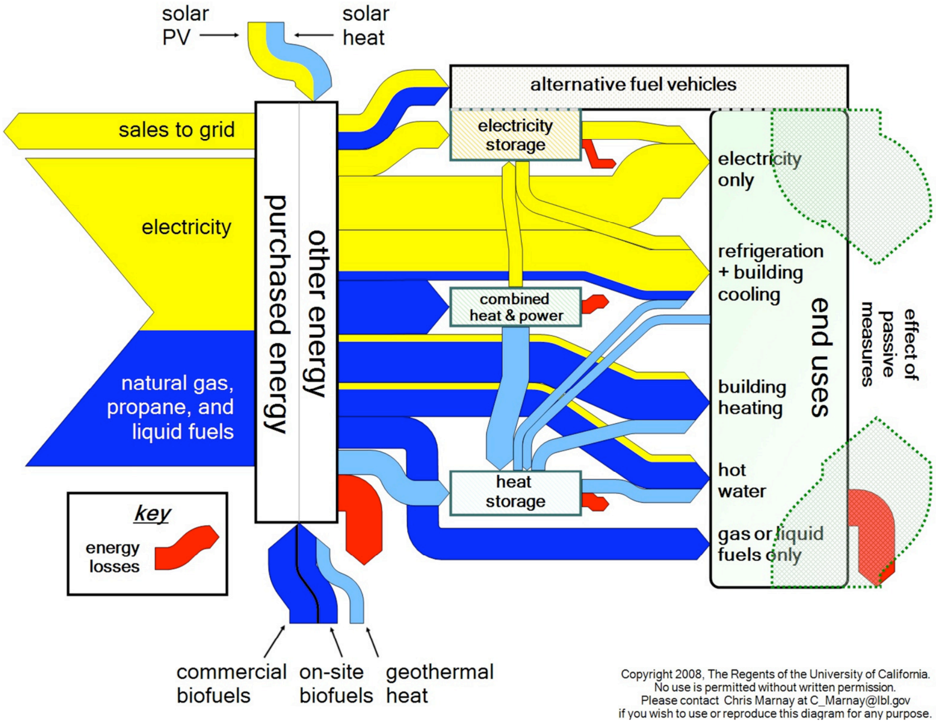

Figure 2. Schematic of energy flows modelled by DER-CAM

Key constraints to the objective function of DER-CAM include:

- Energy balancing, which means total consumption in a given time period must equal total production;
- Total electricity produced is restricted by the amount of installed capacity and, in the case of PV or solar thermal equipment, by available solar insolation or available space for panel installation;
- heat flows, i.e., the useful recovered heat is limited by the amount of waste heat generated and the efficiency of CHP equipment;
- Minimum and maximum levels of charge along with charging and discharging rates of storage technologies influence the amount of available energy;
- Regulatory constraints, such carbon taxes, etc.

DER-CAM supports a multiobjective approach, allowing for the specification of an objective function that is a weighted average between two objectives. In the case that the DER-CAM user intends to minimize costs and CO_2 emissions the objective function of DER-CAM is defined by (1),

$$\min\left(\omega_1 \cdot \frac{Cost}{MaxCost} + \omega_2 \cdot \frac{CO_2 emissons}{MaxCO_2 emissons}\right) \qquad (1)$$

where ω corresponds to the weight to attribute to each objective where $\omega_1 + \omega_2 = 1$ and $0 \leq \omega_i \leq 1$. $Cost$ and $CO_2 emissions$ are the annualized energy costs in \$/year and CO_2 emissions in tCO_2/year, while $MaxCost$ and $MaxCO_2 emissions$ are parameters used to make the objective function dimensionless.

WebOpt

The WebOpt platform represents an effort at LBNL to commercialize a version of DER-CAM, with web-based interface meant to enhance usability and access. For this purpose, a partnership with privately-owned OSIsoft LLC was developed, with the intent of setting up DER-CAM as a web-based “Software as a Service” (SaaS) tool. OSIsoft had previously developed its PI system for collecting, managing and analysing critical real-time operating data of any building.

There are several key benefits to having DER-CAM’s optimization capabilities accessible via WebOpt:

- a graphical interface makes DER-CAM more user friendly;

- running optimizations on LBNL's secure server and returning results to the client means that there is no need for specialized hardware or software on the user side;
- removes the burden of expensive software licensing from end-level user;
- users are not required to enter into licensing agreements with LBNL for accessing the DER-CAM code;
- easy central maintenance of DER-CAM;
- simple user management;
- user tailored DER-CAM version management.

Whenever any user executes WebOpt, he or she does it through a secure Remote Desktop Connection and does not need to have any specialized software installed or run any other program. WebOpt collects data from the LNBL PI server, converts it to the proper DER-CAM format and provides access to both investment & planning and operational week-ahead versions of DER-CAM.

WebOpt currently performs the investment & planning optimization which utilizes historic load data. However, since OSIsoft's PI system does not currently support data feed-back, the optimization results cannot yet be sent back to the building directly. The week-ahead optimization capabilities have been developed in principle, but are not fully implemented in WebOpt. In the week-ahead optimization the building load profiles are forecasted depending on collected weather data.

As a finished service, WebOpt will be a comprehensive SaaS tool, giving users easy access to the full functionality of DER-CAM, and allowing them to utilize the optimized results in conjunction with their existing energy management software. Since DER-CAM is designed in a very open way and can handle different technologies as well as building types, the major limitation for replicating this approach is the data interfacing with the building.

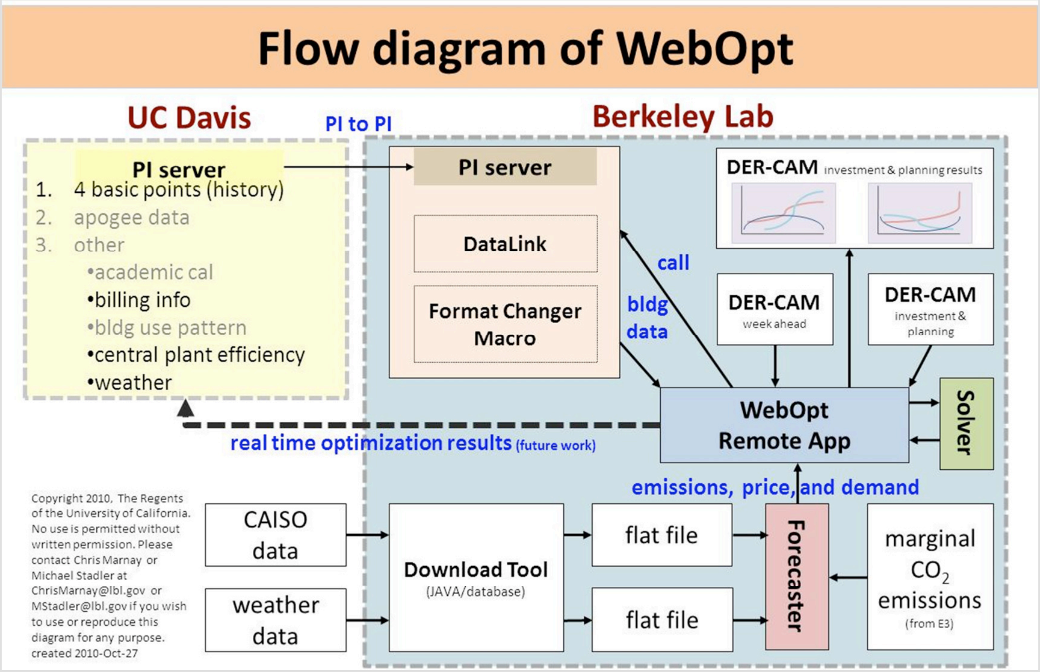

Figure 3. Diagram of WebOpt implementation

Case-Study Project Overview: University of California at Davis

UC Davis was selected as a pilot project for WebOpt. The Segundo Dining Commons building was the first building where the operational week-ahead DER-CAM was tested. Segundo Dining Commons corresponds to a 4 650m^2 dining hall serving three meals a day to students on weekdays and two meals on weekends. Additionally, its kitchen is occasionally used for catering and other campus events and meetings. Approximately two years of historical sub-metered data (electricity, natural gas, steam, and chilled water) for the dining hall have been made accessible for this project. Implementing a full WebOpt week-ahead optimization would require highly integrated network connections and also a number of physical installations. As a result, the current version of WebOpt is tailored to the Segundo Dining Commons building. However, with the appropriate data and data interfacing, WebOpt could be applied to any number of building applications.

UC Davis participation in this project was driven by its motivation to reduce CO$_2$ emissions. The campus currently buys electricity through the Western Area Power Administration (WAPA) at essentially a flat rate of 0.085 $/kWh

(0.066Euro/kWh). Berkeley Lab set out to investigate the hypothetical scenario wherein UC Davis must purchase electricity on a time-of-use (TOU) E-19 tariff from Pacific Gas and Electric (PG&E) and therefore has to consider the variability of CO_2 emissions throughout the day and seasons[2].

Data collection and forecast

The automated operation of WebOpt involves the management of large amounts of data at various levels, namely the historical data from the dining hall, weather data and CO_2 emissions data. Additionally, forecasts of loads, based on a linear multivariate regression, are necessary. The efforts related to data collection, management and forecasting in this project are explained below.

Collected data

Data from UC Davis

Access to site-specific data is a crucial requirement for the implementation of the building optimization. UC Davis utilizes a system capable of accepting data from disparate sources, e.g., enterprise systems, databases, operational data sources, etc. The data system can gather, archive, and distribute real-time data, all key criteria for this optimization project. UC Davis has collected data from its utility meters (electricity, gas, water, steam and chilled water) for the dining hall from April 2009 to present.

Weather Data

Historical weather data and forecasted high and low temperatures for the Davis area are collected for use in building load prediction. The temperature forecast is automatically updated every day.

Marginal CO_2 Emissions Data

Because optimization will consider also carbon reduction, hourly *marginal* emissions data are also collected. These have been derived from simulation of the generation capacity and mix in the Western Electricity Coordinating Council (WECC), and the emissions represent the CO_2 contribution from energy consumed in California regardless of whether the energy was generated in the state or out of state. Emissions are reported for the years 2008 and 2020 for week days and weekend days[3].

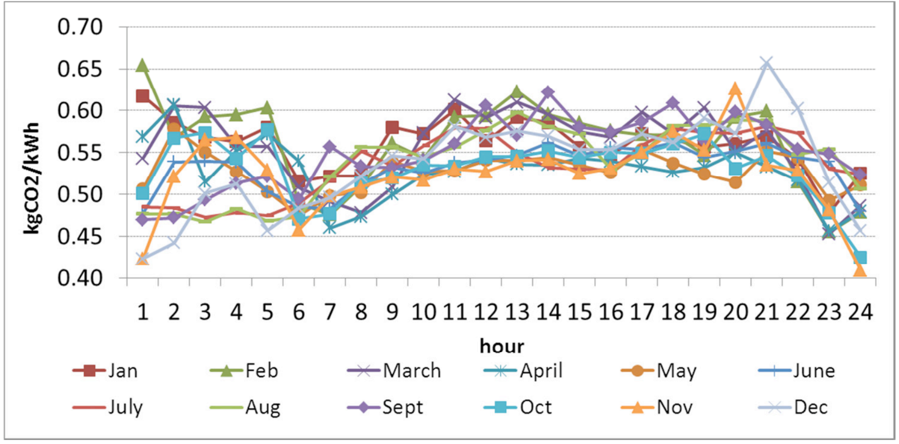

Figure 4. Average marginal hourly CO_2 emissions for week days in 2008. Source: E3

Input Data Forecast

In order for DER-CAM to create an optimal week-ahead operations schedule, a demand forecaster (see Figure 3) has been developed to estimate the heating, cooling, electricity, and natural gas demands that must be met within the next seven days[4]. Given the predicted demands, the week-ahead DER-CAM will create an operation schedule that minimizes cost, emissions, or a weighted combination of the two. Please note that this prediction is not needed for the investment & planning DER-CAM since it uses historic load data.

Energy Demand Forecast for Week-Ahead Optimization

Hourly energy demands were forecasted using a linear multivariate regression on the following factors:

- hour of the day
- daily high temperature

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[2] UC Davis currently purchases all power from WAPA, but some of its auxiliary sites buy from PG&E and Sacramento Municipal Utility District (SMUD). Throughout the mid 2000's, the main campus purchased a mix of PG&E and WAPA power, so the possibility of reverting to a PG&E tariff exists.

[3] Only in the operations week-ahead DER-CAM. The investment & planning DER-CAM uses one marginal emission value of 0.513kgCO_2/kWh.

[4] On an hourly basis.

- daily low temperature
- school day (binary variable)

Interactions of these factors are also considered for the regression, excluding daily low interacting with daily high. To perform this regression, historical energy use and temperature data are used. Current temperature forecasts are downloaded from the internet and updated automatically.

Results

First, the investment & planning DER-CAM was used in the UC Davis project for attaining optimal choices of equipment for the Segundo Dining Commons building. The investment analysis considered the existing flat tariff and an alternative TOU tariff. Then, selected optimal solutions from the first step of analysis were subject to operational examination with the week-ahead version of DER-CAM. Because the data at Segundo Dining Commons building were not disaggregated to a sufficient detail by endues (e.g. refrigeration), conducting detailed demand response analyses were not yet possible. However, the economic effects of *abstract*[5] load shifting were analysed.

Investment analysis

Investments were analysed taking into account two different scenarios; the first one considered the current flat tariff; the second one considered a TOU tariff (see Table 1). The TOU tariff has time-variable energy and power demand charges. For both scenarios a number of technology combinations were modelled. Additionally, two different objectives were considered, minimization of costs (*minCosts*) and minimization of CO_2 emissions (*minCO₂*).

Table 1. PG&E E-19 TOU tariff

Electricity	Summer (May – Oct.)		Winter (Nov. – Apr.)	
	electricity (US$/kWh)	demand (US$/kW)	electricity (US$/kWh)	demand (US$/kW)
max monthly	--	7.70	--	7.70
on-peak	0.16	13.51	--	--
mid-peak	0.11	3.07	0.09	1.04
off-peak	0.09	0.00	0.08	0.00
Fixed (US$/month)	406.57			

Source: PG&E E-19 and own calculations
summer on-peak: 12:00 – 18:00 during weekdays
summer mid-peak: 08:00 – 12:00 and 18:00 – 21:00 during weekdays
summer off-peak: 21:00 – 08:00 during weekdays and all weekends and holidays
winter mid-peak: 08:00 – 21:00 during weekdays
winter off-peak: 21:00 – 08:00 during weekdays and all weekends and holidays

Figure 5 shows multiple results from the analysis of DER investment alternatives for the dining hall building with investment & planning DER-CAM. In order to show the multiobjective results the plot displays both total annual costs in k$ and total annual CO_2 emissions in tCO_2. The multiobjective analysis considers one frontier for each examined scenario, the flat or TOU tariff. As explained above, in a multiobjective approach the objective function is a weighted average between costs and CO_2 emissions, being defined by equation (1). Figure 5 represents both multiobjective frontiers. Every optimization run in the multiobjective frontier is characterized by specific weights, ω_1 and ω_2, respectively attributed to the cost and environmental (CO_2 emissions) functions, considering all possible DER technologies in the optimization. With decreasing ω_1, which means increasing focus on CO_2 emissions, the annual energy costs increase and the emissions go down. The starting point of each multiobjective frontier is the do nothing (DN) case, both for flat and TOU tariff. In the case of the flat tariff, the DN represents the base case (BC). Both cases bear similar CO_2 emissions, however, using the flat tariff results in lower annual costs. At the bottom of the graph, markers S1 and S2 represent the pure cost optimization solutions, which means they are characterized by $\omega_1=1$, $\omega_2=0$. Points S3 and S4 are pure CO_2 minimization solutions. Their performance in terms of the two objectives is very similar, being S3 marginally less expensive. Please note that Figure 5 shows also sub-optimal solutions, e.g. S5 with only PV, solar thermal and heat storage allowed as possible options. Since not all possible DER technologies are allowed in the optimization, this case does not reach S3 and is on the right hand side of the frontier.

Most *minCost* solutions bear significant CO_2 emissions, i.e. they are mostly located in the right-bottom of the graph. On the other hand *minCO₂* solutions adopting more DER technologies are located in the upper-left corner of the

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[5] Since no detailed building automation system data for the different shiftable loads was available an abstract load shifting was assumed that allows 15% of the electric load in any hour to be rescheduled to any other hour of the same day. No more than 40kW of electricity can be transferred in any hour.

diagram. Results show that the current flat tariff is highly economical. From an economic point of view only one DER investment was found to be attractive compared to the base case (BC) with the flat tariff and no DER adoption, the adoption solar thermal collectors for heating loads (point S1 in Figure 5). This means that no electricity loads are economically served by DG investments. In other words, the low flat rate makes the purchase and installation of equipment for delivering electricity not very economically attractive.

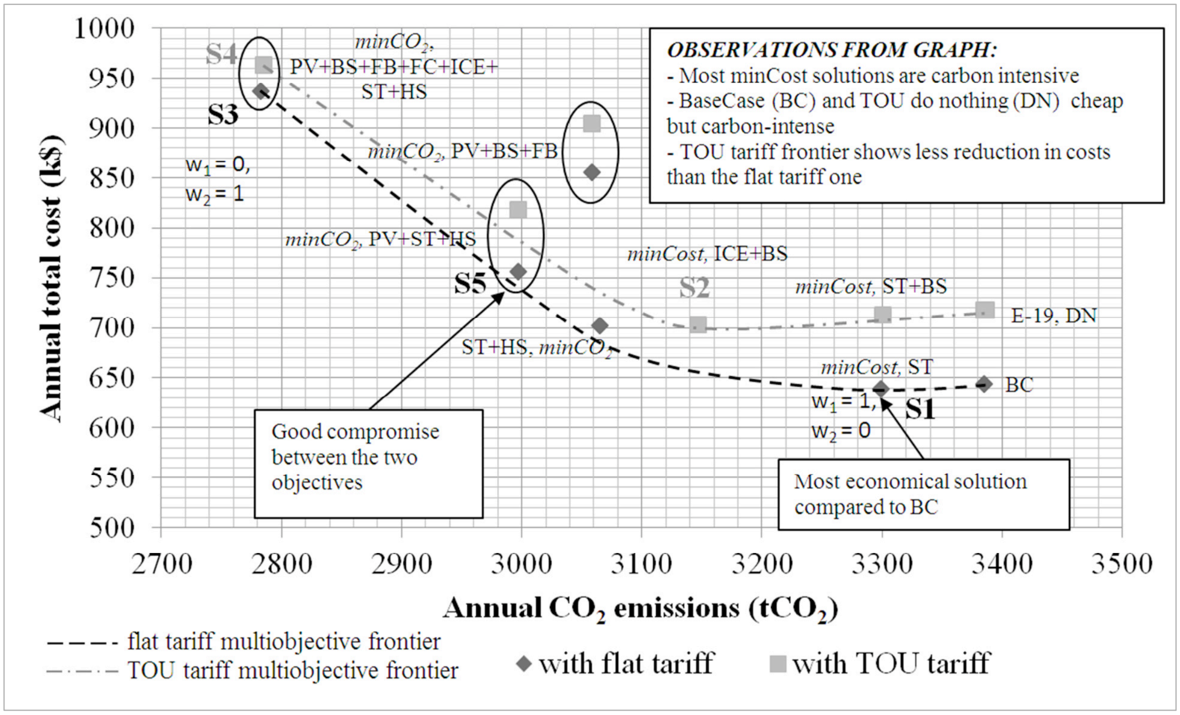

Figure 5. Plot of multiple solutions calculated by investment & planning DER-CAM for Segundo Dining Commons building. *Diamonds represent solutions considering the current flat tariff while squares relate to the alternative TOU tariff. Notes on abbreviations: PV: photovoltaic, BS: conventional lead acid battery, FB: Zinc Bromine flow battery, FC: fuel cell with waste heat utilization, ICE: internal combustion engine with waste heat utilization, ST: solar thermal conventional collectors, HS: Heat storage, BC: Base case, and DN: "Do nothing" case, where all energy needs to be purchased from the utility and no DER adoption is allowed. S1 through S5 represent specific scenarios discussed in this investigation.*

In the cases of PV and ST the amount of panels installed is constrained by the available roof space of the dining hall building, of 2 100m^2. S5 could represent an attainable compromise between both objectives, even if there is an increase in costs. So, if UC Davis were looking forward to invest in a decreasing CO_2 emissions mix of equipment without great negative effects in annual costs, S5 could be a good compromise for that purpose.

Table 2 summarizes the major results attained with WebOpt for the investment decision. Due to the favourable flat tariff implemented in the case-study building it is noticeable that the potential for CO_2 emission abatement is higher than the expected annualized cost reductions by the introduction of DER. In general, all the explored solutions have resulted in a decrease of CO_2 emissions.

For performing the investment runs, a number of assumptions were taken into account. The considered technologies in WebOpt were natural gas powered internal combustion engines and fuel cells, both equipped with CHP capabilities, photovoltaic panels, solar collectors, heat storage devices, conventional (lead-acid) and flow (zinc-bromine) batteries. Advanced cooling technologies such as absorption chillers and refrigeration were not taken into account due to the existence of a centralized chilled water-based system. However, it is assumed that the Segundo Dining Commons building can serve the centralized cooling system with electricity[6]. The electricity only load, e.g. computing never exceeds 270kW at the dining hall, but considering the 60kW maximum cooling load[7] explains the adoption of 250kW of FCs and 180kW of ICEs (see Table 2)[8].

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[6] The COP of the centralized cooling system is assumed to be 4.5.

[7] In terms of electric load.

[8] However, in such cases the purchased equipment needs to run in part load.

Table 2. Important solutions of the investment problem at the Segundo Dining Commons building

Solution	Adopted technologies[9] (kW or kWh)	Total annual costs (k$ and kEuro)	Cost abatement (k$, kEuro and % of BC)		Emissions (t of CO_2)	CO_2 abatement (tCO_2 and % of BC)	
Base case (BC)	N.A.	645 (500)	N.A.		3 385	N.A.	
S1	293kW ST	640 (496)	5 (4)	0.8%	3 299	86	2.5%
S2	250kW ICE, 27kWh BS	703 (545)	-58[10] (-45)	-9.0%	3 147	238	7.0%
S3	245kW PV, 110kWh BS, 58kWh FB, 250kW FC, 180kW ICE, 373kW ST, 1158kWh HS	938 (727)	-293 (-227)	-45.4%	2 783	602	17.8%
S4	246kW PV, 177kWh BS, 54kWh FB, 250kW FC, 180kW ICE, 370kW ST, 1079kWh HS	963 (747)	-318 (-247)	-49.4%	2 785	600	17.7%
S5	170kW PV, 742kW ST, 2824kWh HS	756 (586)	-112 (-87)	-17.3%	2 997	388	11.5%

The total annual costs include all DG-related costs during a typical year, including capital, fuel costs, operation, and maintenance costs.

In the general WebOpt optimization settings, the interest rate for investments was set to 6% and the maximum payback period for any project is 12 years. Tables 3, 4, and 5 describe the technology parameters which were assumed in the runs described above.

Table 3. Storage, photovoltaics and solar thermal cost characteristics used in the investment & planning DER-CAM runs

Technology	Fixed cost ($)	Maintenance variable cost ($/kWh)	Maintenance fixed cost ($/kWh)	Lifetime (years)
Lead-acid battery	0	200	0.0	6
Generic heat storage	10 000	100	0.0	17
Zinc-bromine flow battery energy	0	220	0.1	10
Zinc-bromine flow battery power	0	2 125 ($/kW)	0.0 ($/kW)	10
Photovoltaics	0	8 300 ($/kW)	0.3 ($/kW)	20
Solar thermal	1 000	400	0.1	15

Source: EPRI-DOE, Schoenung et al. 2003, SGIP 2008, and Stadler et al. 2009a

Table 4. Technical characteristics of storage technologies used in the investment & planning DER-CAM runs

Parameter	Lead-acid battery (%)	Zinc-bromine flow battery (%)	Heat storage (%)
Charging efficiency	87	84	90
Discharging efficiecy	87	84	90
Decay rate	0.4	0.0	1
Maximum charging rate	20	N.A.	25
Maximum discharging rate	40	N.A.	25
Minimum state of charge	30	25	0

Source: EPRI-DOE, Schoenung et al. 2003, SGIP 2008, and Stadler et al. 2009a

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[9] PV: photovoltaic, BS: conventional lead acid battery, FB: Zinc Bromine flow battery, FC: fuel cell with waste heat utilization, ICE: internal combustion engine with waste heat utilization, ST: solar thermal conventional collectors, HS: Heat storage.

[10] A minus indicates a cost increase compared to the BC.

Table 5. Technical characteristics of the natural gas fired CHP DG units adopted

Technology	Rated power (kW)	Capital cost ($/kW)	Maintenance variable costs ($/kWh)	Electric efficiency (%)	Heat-to-power ratio	Lifetime (years)
Small ICE with heat exchanger	60	3580	0.018	29	1.73	20
Medium ICE with heat exchanger	250	2180	0.013	30	1.48	20
FC with heat exchanger	250	2700	0.029	36	1.00	10

Source: SGIP 2008 and Stadler et al. 2009a

Week-ahead operation scheduling analysis

The optimal solutions from S1 to S4 (see Table 2) were investigated and subject to the operational weak-ahead optimization for the week from Sunday 09-Jan-11 to Sunday 16-Jan-11. The *minCost* investment solutions S1 and S2 were subject to cost minimizing scheduling, while the *minCO2* solutions S3 and S4 were subject to carbon minimization. However, only the interesting cases are shown here.

The operation schedule for the week ahead, which resulted from the load and operational forecasting optimization from DER-CAM is shown in following figures.

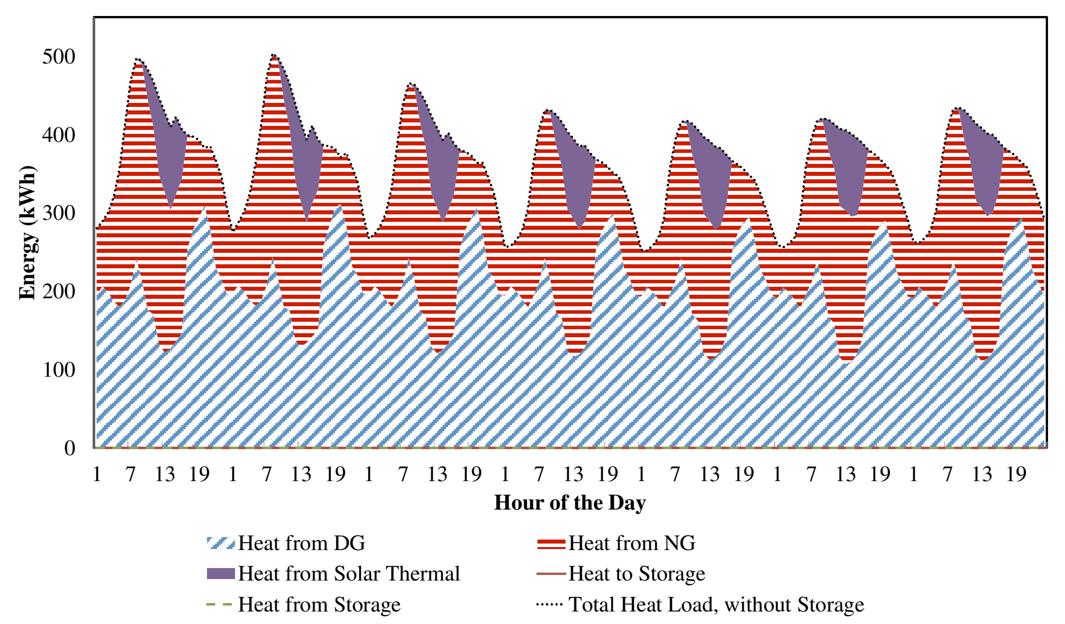

Figure 6. Forecasted heat demand and CO_2 minimizing operation schedule for the S3 case and the week from Sunday 09-Jan-11 to Sunday 16-Jan-11

In this S3 case, internal combustion engines and fuel cells are purchased, both featuring CHP capabilities, and it is visible from Figure 6 that these technologies contribute a lot to the heat supply of the building (area at the bottom of Figure 6). Additionally, solar thermal collectors are also used during daytime. Due to weather and load conditions DER-CAM chooses not to operate heat storage during this considered week.

In terms of electricity supply, it is visible in Figure 7 that photovoltaic operates during daytime, for providing CO_2 emission free energy as much as possible. The internal combustion engines provide the building with the remaining electricity supply. However, both the lead-acid and flow batteries are not used in the considered week, with one exception where the installed natural gas fired units couldn't satisfy all the electricity needs and DER-CAM chose to use storage. Minimizing CO_2 emissions, in the considered week, results in no utility electricity consumption. Please note that the fuel cell is not used in this particular week due to the required minimal operation level of 125 kW which is not attained[11]. The internal combustion engine has only a minimum operations level of 30kW, and therefore, the less environmental friendly internal combustion engines are used.

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[11] Due to a lack of cooling loads. It is assumed that the Segundo Dining Commons building can serve the centralized cooling system with electricity.

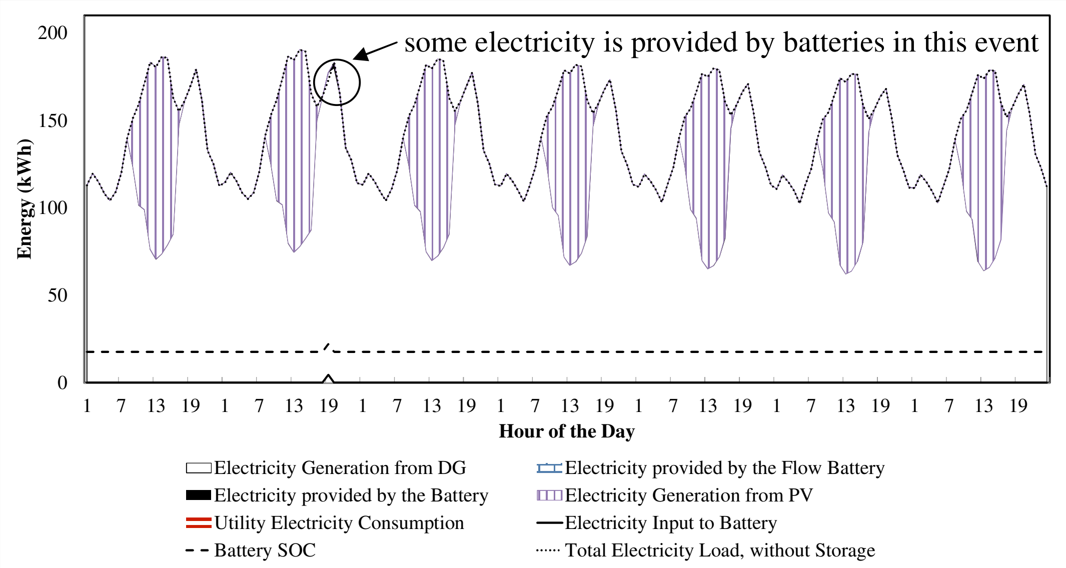

Figure 7. Forecasted electricity demand and CO_2 minimizing equipment operation schedule for the S3 case and the week from Sunday 09-Jan-11 to Sunday 16-Jan-11. *SOC means state of charge.*

Additional runs considering the TOU tariff were undertaken, considering the technology choices suggested by DER-CAM in S2 and S4. The *minCost* solution S2 considers the purchase of 250kW ICE and 27kWh of lead-acid batteries. Figures 8 represents the forecasted energy needs and operational schedule for this case.

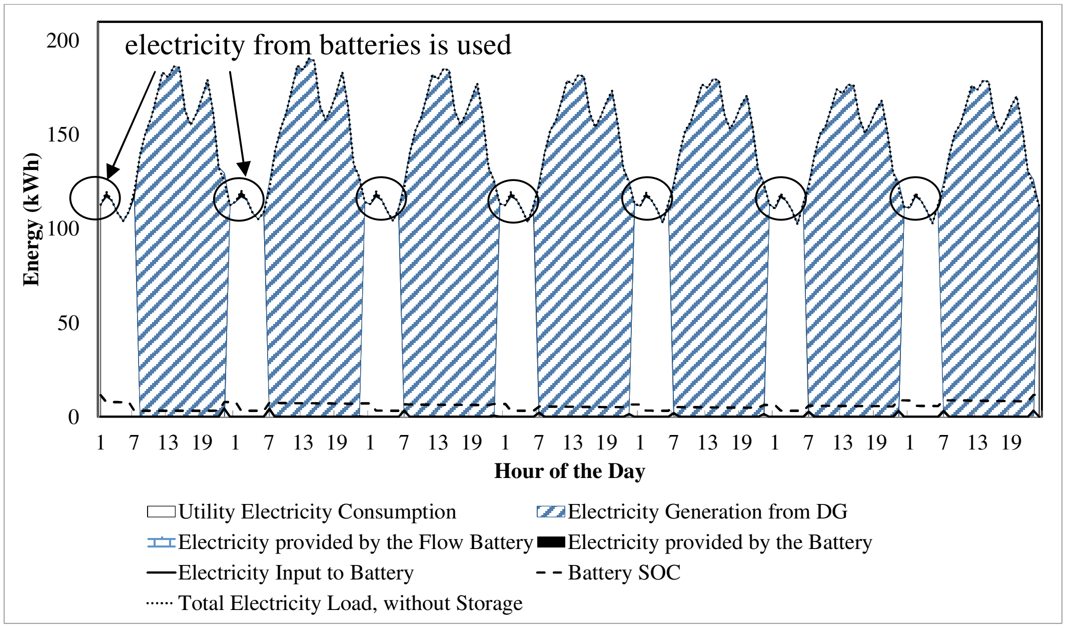

Figure 8. Forecasted electricity demand and cost minimizing operation schedule for the S2 case and the week from Sunday 09-Jan-11 to Sunday 16-Jan-11

Figure 8 demonstrates how DER-CAM chooses to run the DG equipment during most time of the day with the exception of night hours when electricity is cheaper. Still, during some periods DER-CAM makes use of the installed storage equipment in order to avoid TOU max monthly demand charges when the internal combustion engines are not running. Batteries will be charged when demand is low. However, as already noted, the loads at this time of the year are still low compared with other periods and it is likely that the batteries will be much more used during the summer.

Load rescheduling analysis

The effect of *abstract* load rescheduling of electricity was also analysed for the *minCost* solution S2 with internal combustion engine maintenance, which considers the adoption of the TOU tariff. Due to the maintenance it is assumed that only 60kW of ICEs are available. In this case, DER-CAM's load shifting algorithm will reschedule electricity to hours where energy use would be cheaper. As can be seen in Figure 9, DER-CAM flattens the utility electricity consumption and reduces both volumetric and demand charges of the electric bill.Some load is supplied by using batteries (see black areas in Figure 9 early in the week).

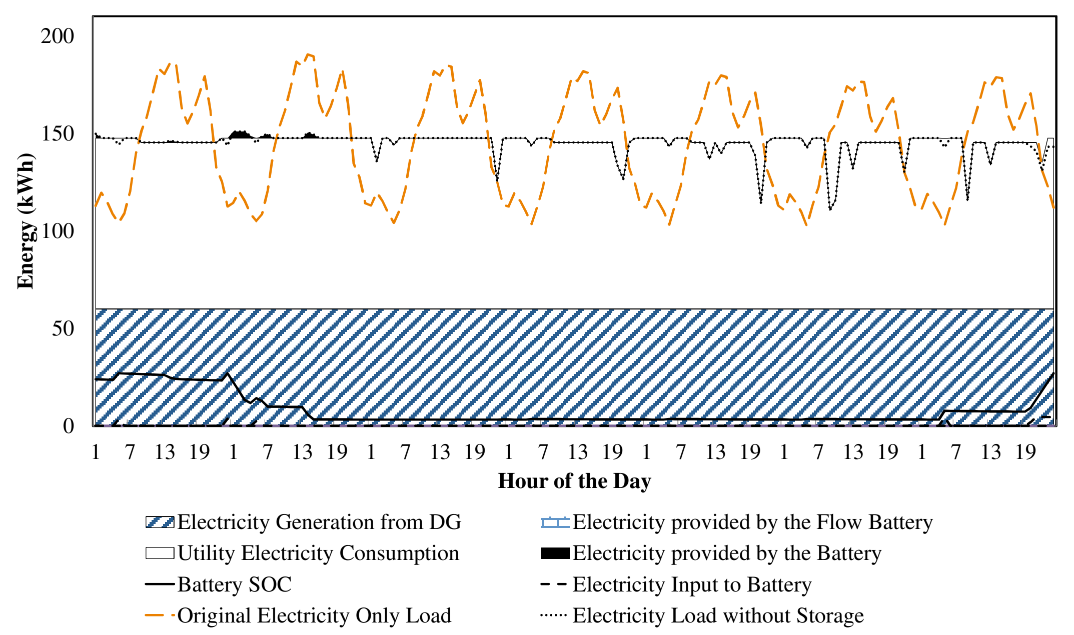

Figure 9. Forecasted electricity demand and cost minimizing operation schedule for the S2 case and for 14-Jan-11[12] to 21-Jan-11, considering abstract load shifting

Due to load shifting volumetric electricity charges, for the considered week, are reduced by marginal values of around $17 (13 Euro). However, monthly peak demand charges are reduced by $343 (257 Euro). The additional effects on CO_2 emissions are negative in this case[13] and they increase slightly by about 355kg of CO_2[14]

For this abstract experiment, the assumptions put into place are that up to 15% of the electricity used in any hour at the building can be rescheduled to any other hour of the same day and that no more than 40kW of electricity can be transferred to any other hour. Of course, this assumption highly influences the results, but due to insufficient data no real shiftable load data was available.

Conclusions

With the development of WebOpt, LBNL hopes to provide broad access to the functionality of its DER-CAM optimization software. Using the Software as a Service model, WebOpt is available via a user-friendly interface without the need to specialty software or expensive licenses. As a result, facility managers now have a powerful tool for informing their DER investment decisions. Optimizations can be conducted on the basis of cost or carbon emissions. WebOpt also provides the ability to generate optimized week-ahead schedules based on predicted loads. With the appropriate software and support, automated scheduling can be generated, to ensure efficient and low-carbon operation of DER equipment.

The pilot project at UC Davis represents the first step in the commercialization of DER-CAM. With its implementation at the Segundo Dining Commons, the value of WebOpt has been demonstrated both in the selection of technology and its consequent operations. The potential for load shifting has also been investigated. Currently, the data interfacing of WebOpt is tailored specifically to UC Davis, however, as development continues, its applicability will increase across the United States and beyond.

Future work will focus on resolving issues experienced during the pilot project, particularly, ensuring that sufficient data exists to leverage DER-CAM to its full usefulness. Additionally, LBNL will work with project partner OSIsoft to create a robust feedback functionality to the building's energy management system, so that optimized operations schedules can be utilized in an automated manner.

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[12] Please note operations DER-CAM uses real time, and therefore, the time when the runs were done is reflected in the figures. Since the runs for Figure 9 were done on 13-Jan-11, Figure 9 starts on 14-Jan-11.

[13] The LBNL team did also a run starting on 15-Jan-11 and then the change in CO_2 emissions is almost zero.

[14] All results are compared to the modified S2 case with only 60kW ICE available.

References

E3, http://www.ethree.com/public_projects/ghg.html

EPRI-DOE Handbook of Energy Storage for Transmission and Distribution Applications, EPRI, Palo Alto, CA, and the U.S. Department of Energy, Washington, DC: 2003. 1001834

Microgrid Symposiums. Held at Berkeley, CA, USA in June 2005, Montréal, Canada in June 2006, Nagoya, Japan in June 2007, Kythnos, Greece in June 2008, San Diego, CA, USA in June 2009 and Vancouver, Canada in June 2010 (Available at http://der.lbl.gov)

PG&E E-19, http://www.pge.com/tariffs/tm2/pdf/ELEC_SCHEDS_E-19.pdf

Schoenung S. M. and W. V. Hassenzahl (2003), "Long- vs. Short-Term Energy Storage Technologies Analysis, A Life-Cycle Cost Study, "Sandia Report SAND2003-2783 Unlimited Release, August 2003

SGIP (2008), Statewide Self-Generation Incentive Program Statistics, California Center for Sustainable Energy, http://www.sdenergy.org/ContentPage.asp?ContentID=279&SectionID=276&SectionTarget=35, updated December 2008

Siddiqui, A.S., R. Firestone, S. Ghosh, M. Stadler, C. Marnay, and J.L. Edwards, (2003), "Distributed Energy Resources Customer Adoption Modeling with Combined Heat and Power Applications", Lawrence Berkeley National Laboratory Report LBNL 52718

Stadler, M., C. Marnay, A. Siddiqui, J. Lai, and H. Aki, (2009), "Integrated Building Energy Systems Design Considering Storage Technologies", 2009 ECEEE Summer Study, June 2009, La Colle sur Loup, France.

Stadler, M., C. Marnay, G. Cardoso, T. Lipman, O. Mégel, S. Ganguly, A Siddiqui, and J. Lai (2009a),. "The Carbon Dioxide Abatement Potential of California's Mid-Sized Commercial Buildings," California Energy Commission, PIER Program, CEC-500-07-043, 500-99-013, LBNL-3024E, December 2009

Stadler, M., A. Siddiqui, C. Marnay, H. Aki, and J. Lai, (2009b), "Optimal Technology Investment and Operation in Zero-Net-Energy Buildings with Demand Response", 22nd Annual Western Conference, Advanced Workshop in Regulation and Competition, June 2009, Monterey, California

The PI System - the industry standard in enterprise infrastructure for management of real-time data and events, available at: http://www.osisoft.com/software-support/what-is-pi/what_is_pi_.aspx

The XE Universal Currency Converter, available at: http://www.xe.com/ucc/

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