A DISTRIBUTED INTELLIGENT AUTOMATED DEMAND RESPONSE

BUILDING MANAGEMENT SYSTEM

Quarterly Progress Report

January 25, 2011

1 DOE Award Number & Name of Recipient

1.1 DOE Award Number:

DE-FOA-000115

1.2 Recipient:

Regents of the University of California, (UC Berkeley campus), with Lawrence Berkeley National Lab and Siemens Corp as sub-awardees.

2 Project Title and Principal Investigators

2.1 Project Title:

A DISTRIBUTED INTELLIGENT AUTOMATED DEMAND RESPONSE BUILDING MANAGEMENT SYSTEM

2.2 Principal Investigators:

Professor David Auslander (PI)
Department of Mechanical Engineering, U.C. Berkeley

Professor David Culler (co-PI)
Department of Electrical Engineering, U.C. Berkeley

Professor Paul K. Wright (co-PI)
Director, Center for Information Technology Research in the Interest of Society (CITRIS)
and the Department of Mechanical Engineering, U.C. Berkeley

Dr. Yan Lu (PI for Siemens Corp.)
Siemens Corporate Research Inc

Ms. Mary Ann Piette (PI for LBNL)
Lawrence Berkeley National Laboratory

3 Reporting Dates

3.1 Date of Report:

25 January 2011

3.2 Period Covered:

1 October 2010 – 31 December 2010

4 Comparison of Project Accomplishments and Project Goals

The outlined goals of the project for the fourth quarter (October 1, 2010-December 31, 2010) consist of four major tasks: the determination of the functional requirements, and the architectural design for the project (Task 2), the development of a Service-Oriented Architecture (SOA) for Distributed Intelligent Automated Demand Response (DIADR) (Task 3), BMS OpenADR Integration (Task 4), and the development of Demand Response Algorithms (Task 5). The following paragraphs outline the means of completing the stated tasks and the progress that has been made thus far on the Distributed Intelligent Automated Demand Response project. In addition, the following section describes preliminary work in preparation for Task 6 and Task 8.

The subcontract to SCR was nearly finalized this quarter, and is expected to be complete early next quarter.

The remaining subtask of Task 2, development of the functional requirements and the architectural design for the DIADR project, was to document the functional requirements of the DIADR system. A report entitled System Architecture, was submitted in late October that describes Sutardja Dai Hall and its Apogee Building Energy Management System, applicable methods such as the development of a baseline, functional requirements such as communication protocols, the DIADR system architecture, the Service Oriented Architecture using a modification of an existing residential gateway, and test scenarios.

The development of a Service Oriented Architecture (SOA) for DIADR (Task 3) began this quarter and will continue into the next quarter. Rather than develop new material, it was decided to build upon the existing residential distributed load control gateway developed at UCB. This gateway can manage distributed load control, down to the plugload level in an individual office. Three of the six subtasks for Task 3 were scheduled for this quarter. The first subtask is the SOA implementation plan, which is to modify the existing gateway for this use. The second subtask involves plan verification and adjustment; the adjustment in this case refers to the development of interface with the Siemens Smart Energy Box, which will continue into next quarter. The third subtask requires porting the SOA to selected hardware platforms, and will also continue into next quarter.

BMS OpenADR Implementation (Task 4) was completed this quarter. The test and demonstration were held at Sutardja Dai Hall at the University of California Berkeley on November 12, 2010. During the demonstration, Siemens used a stand-alone device—the Siemens Smart Energy Box—to connect the

CITRIS BMS with LBNL DRAS server based on BACnet and OpenADR protocols. The test result shows that we have successfully enhanced the CITRIS Siemens Building Management System as Open ADR ready and met Milestone 2 of DIADR project due on November 17, 2010. A report on the OpenADR integration test was delivered to DOE at the end of November.

Developing Demand Response Algorithms (Task 5) began this quarter. UCB and Siemens held a technical discussion on the control architecture design in mid-December. Development of the central load management optimization algorithms and the distributed DR algorithms has commenced and will continue into the next quarter.

5 Major Activities, Significant Results, Major Findings

On October 5, 2010, a kick-off meeting was held at UC Berkeley. Presentations were made by the Department of Energy, UC Berkeley, Lawrence Berkeley National Laboratory, and Siemens Corporation. Amy Tomer described the National Energy Technology Laboratory of DOE. Prof. Paul Wright presented an overview of CITRIS and i4Energy. Prof. Dave Auslander outlined the projects objectives and methods and Dr. Yan Lu discussed the contribution of Siemens Corp. Sila Kiliccote then described contributions from LBNL. Dr. Gary Baldwin discussed the project risks, management and budget, while Prof. Auslander outlined project risks and risk management. Prof. David Culler, Sila Kiliccote, and Prof. Dave Auslander presented related projects.

5.1 Task 2.0-- Identify System Requirements and Develop System Architecture

A document describing the details of the system architecture was submitted in late October. This report discusses the components of the system, including the repurposing of the existing residential energy gateway for distributed load control and development of the Siemens Smart Energy Box as a gateway between utility signals and building control systems. Figure 1 below shows the main components of the system architecture: a demand response signal is initiated at LBNL's DRAS server. The Siemens Smart Energy Box receives the message and communicates the signal to the Apogee, WattStopper and distributed load control gateways.

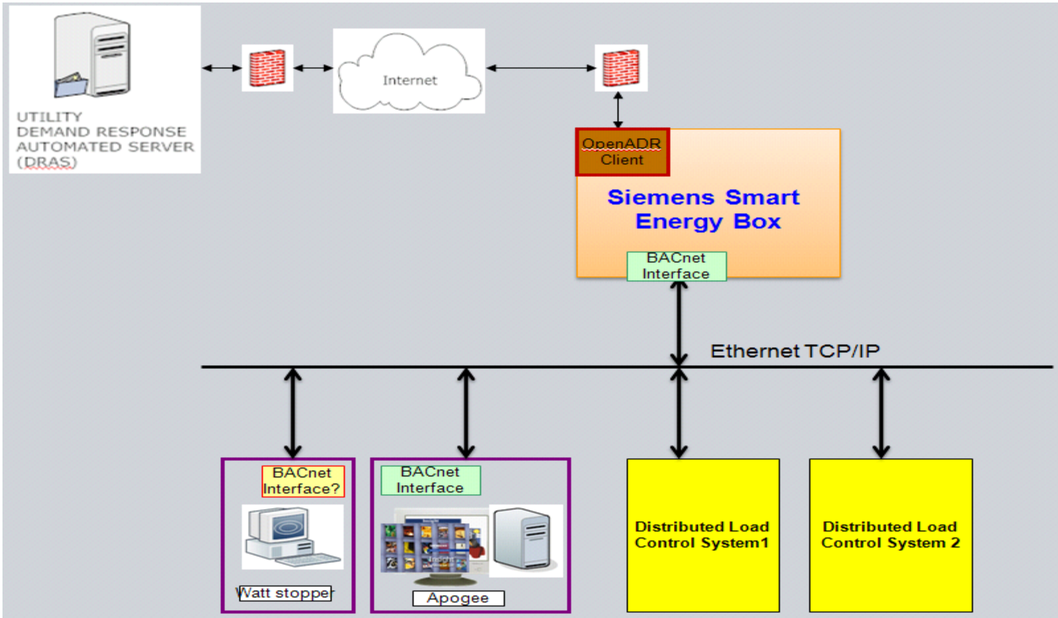

Figure 1: System Architecture for Sutardja Dai Hall.

5.2 Task 3.0—Develop Service Oriented Architecture (SOA) for DIADR

Siemens Research is supporting UCB in developing control interfaces and communication protocols between the central load control and the distributed load control. A residential energy gateway project (developed for a separate project in the Department of Mechanical Engineering at U.C. Berkeley) has provided the backbone for the foundations of a distributed demand response load control gateway for commercial loads. The system focuses on two-way communication between smart meters and appliances using an OSGI framework.

Figure 2 below shows the relationship between the Automated Demand Response (ADR) signal, the Smart Energy Box (SEB) and the distributed load control system or gateway, and that between the gateway and its constituent loads.

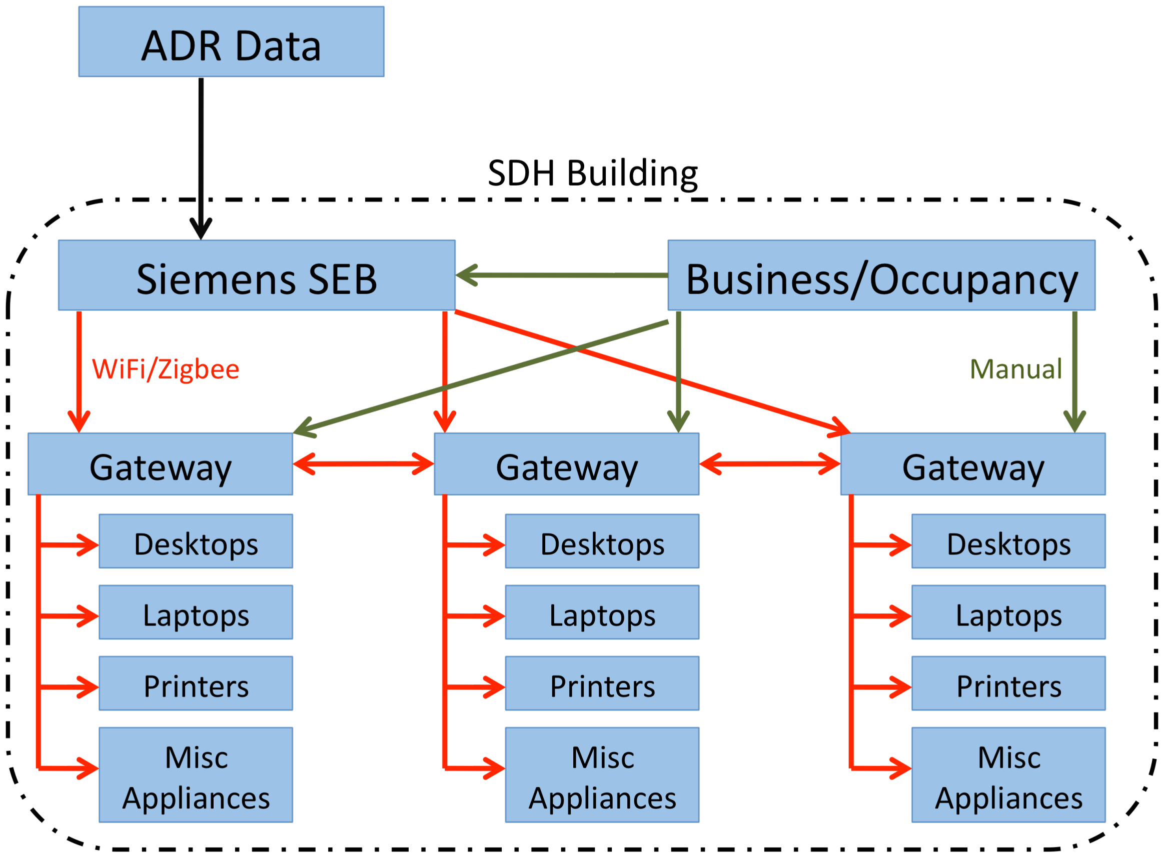

Figure 2: Distributed Load Control and External Central Load control Integration Platform

Work this quarter consisted of developing the communication architecture for the gateway. One part is server/client programming, where the server (gateway) communicates with various clients (devices or appliances). This programming includes time synchronization (between the gateway and all the devices connected to it) and network communication. Time synchronization is important to ensure that tasks will be executed at the expected time and historic data on energy consumption has the correct time. Network communication allows the gateway (programmed in Java) to communicate to any other device in any programming language. A JNI (Java Network Interface) was implemented to allow network communication between Java and C++ or C#.

Another piece of the communication architecture is the database. Effort this quarter consisted of researching for a suitable backend database to house all the energy, account, and user preference data for both the gateway as well as for the website interface. After considering all the different types of databases from relational to object-oriented, key features offered by different distributors and taking size, price, efficiency of implementation, scalability, usability, and reproducibility into account, it was determined that for the purposes of future standardization and integration of the gateway, MySQL and its embedded version, SQLite, would be the best choice. Bundles were then developed to export historical data to the MySQL/SQLITE database; databases were developed to compile user preference data for DR events.

The other part of the communication architecture lies between the gateway and the Smart Energy Box. UCB is working with Siemens to develop and refine the communication protocols between the gateway and the Siemens Smart Energy Box (SEB).

5.3 Task 4.0—BMS OpenADR Integration and central load control strategy development

Siemens developed the Smart Energy Box (SEB) as a building to grid connection. It can receive a signal from the power grid (OpenADR client) and automatically moderate the actions on building automation systems (BMS Adapter) based on the weather forecast and building energy modeling. Figure 3 shows the basic four function modules provided by the SEB. Efforts this quarter focused on developing and testing the BMS adapter and OpenADR Client in the lab and in Sutardja Dai Hall, and enabling the weather data adaptor and energy simulation plug-ins. In the next quarter the third party plug-ins for the WattStopper lighting control and distributed load gateway will be developed.

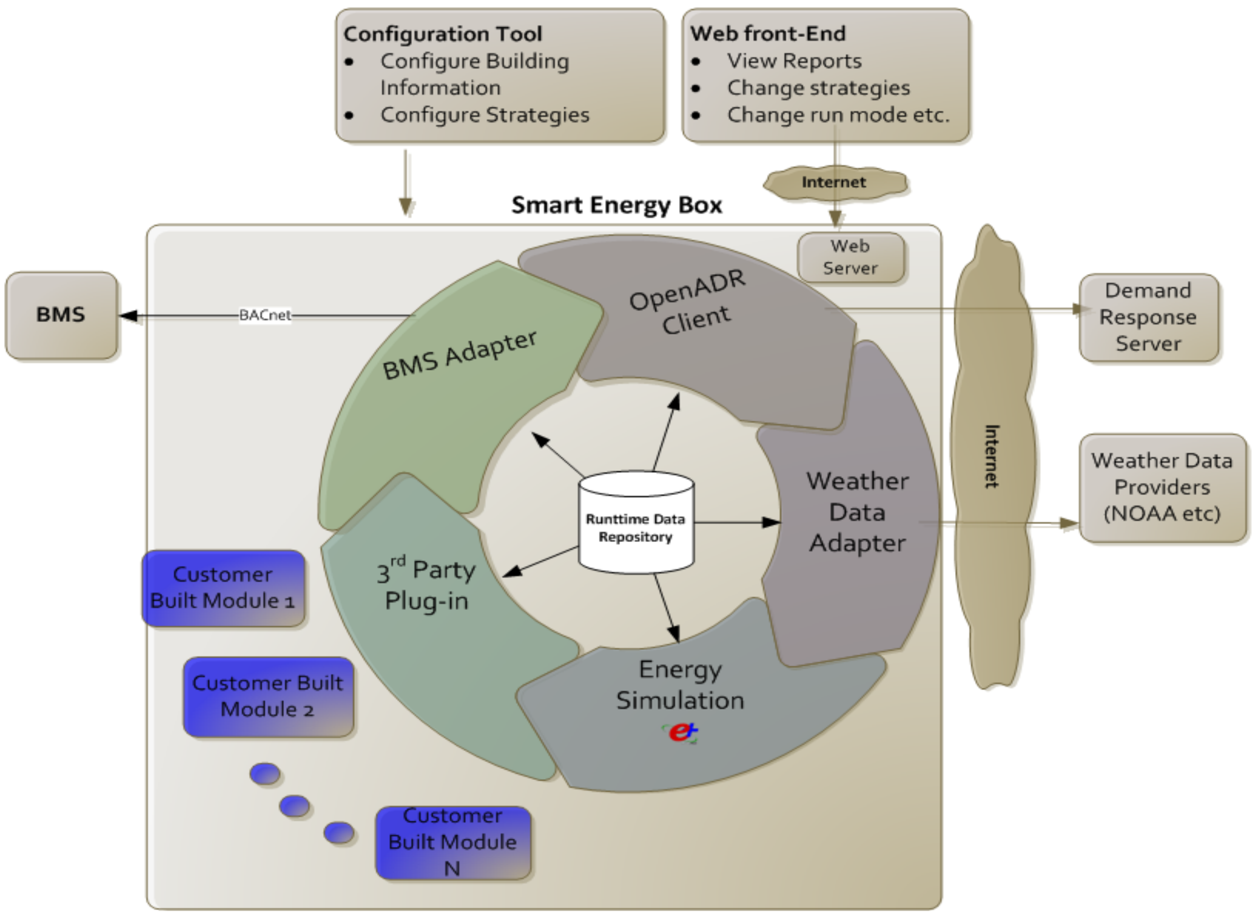

Figure 3: Architecture of the Siemens Smart Energy Box

On November 10-12, 2010, Thomas Gruenewald and Prasad Mukka from Siemens installed and tested the Smart Energy Box. See Figure 4 below. First, they established network connections, both remote access to the SEB and access to LBNL DRAS server. They ran initial tests with the SEB and Apogee at Sutardja Dai Hall (CITRIS building). Then they worked with Sila Kiliccote to test with LBNL DRAS server, to configure DR test events. First the DR event is scheduled with the date and time; the DRAS server issued a “pending” signal. At the start of the event, the DRAS server signalled the event, either “high” or “medium”. The SEB triggered a demand response sequence, in this test case, relayed the message to the Apogee system to increase the temperature setpoint in Room 464 either 4 or 2 degrees Fahrenheit respectively. At the end of the event, the DRAS server issued a “normal” signal, which the SEB received and triggered a recovery strategy, in this case to resume normal setpoint temperature. The system was successfully demonstrated to the other project members.

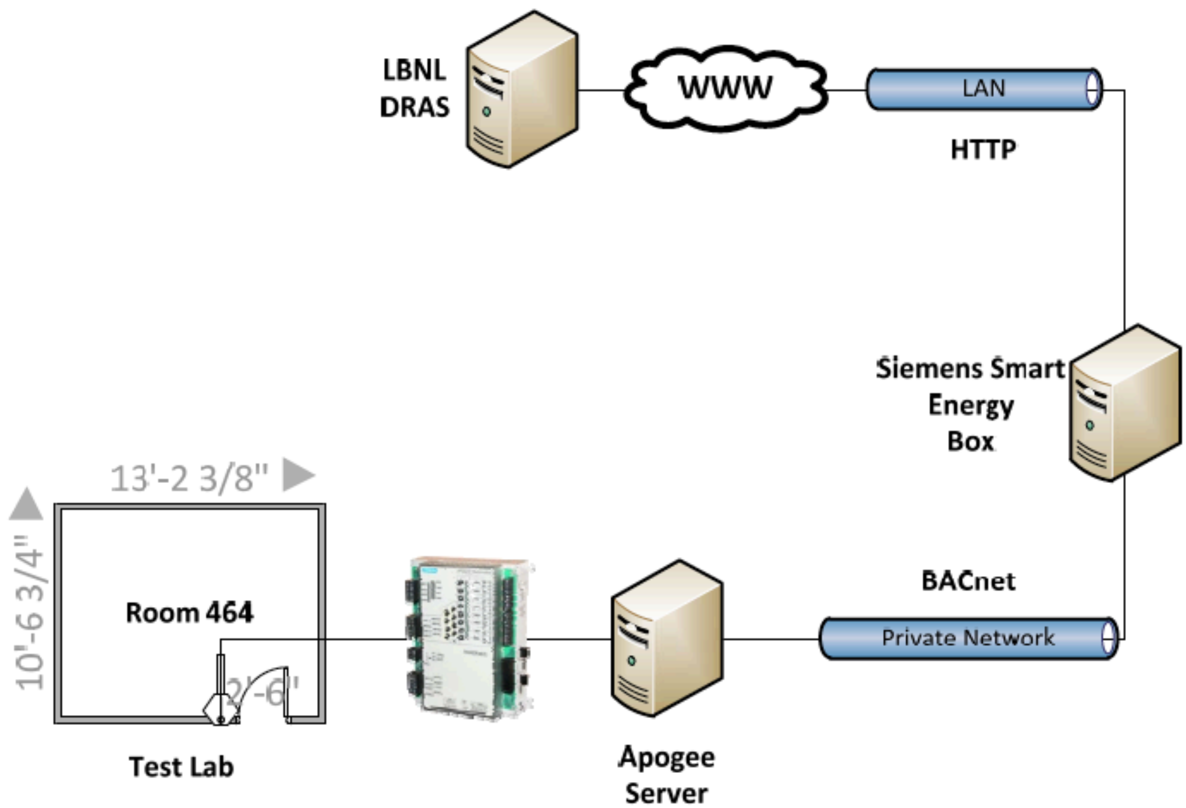

Figure 4: Configuration of the BMS OpenADR test.

5.4 Task 5.0—Developing Demand Response Algorithms

This quarter, DR algorithm development commenced at the whole building systems level as well as the distributed load control level. In support of the DR algorithm development, a plug load inventory of the office space was planned and an interview with the facilities manager was conducted to determine DR-controllable points in the building.

5.4.1 Plug load inventory: the energy audit

UCB planned a full inventory of the plug loads in Sutardja Dai to analyze the power ratings of all the appliances in the office sector of the building. This energy audit will yield an understanding of the dynamics of the building and the environmental setting of occupants on each floor. The inventory will be stored in a database. The database will provide information useful for the energy assessment of the building as it relates to the EnergyPlus model, and will also allow researchers to determine the pattern of energy usage movement throughout the building.

This quarter the decision was made to automate the process using an innovative method called Rapid Auditing Protocol (RAP) developed as a collaboration between researchers at CITRIS and loCAL groups. The method uses QR codes (Quick-Read, matrix or two dimensional barcodes) in order to label items (e.g. location (floor, room), type of appliance) in the building, and enters information on each device via a smart phone database application. The Rapid Auditing Protocol (RAP) allows researchers to energy audit the building in a continuous fashion, and will lead to effective demand response through improved user involvement and awareness of energy usage throughout the building. The protocol involves the following steps:

1. Record Device Information:
    a. Power usage
    b. Local coordinates (relative to room origin [west,north]
    c. Device power draw or amperage rating
    d. Device make and model number
    e. Device type (place in taxonomy)
    f. Extra information
2. Scan device QR code (unique for each device)
3. Take picture of device
4. Enter device in database

This energy auditing protocol can place each device in the database in approximately a minute, and is very useful for assessing the energy usage of the building on a room by room, floor by floor basis.

Figure 5: Example RAP QR Code

The database was designed and built based on StreamFS, which describes hierarchical metadata management with symbolic links and piping for streaming sensor data. The application was developed and tested. The location QR codes were affixed to offices and floors of the building, and mapped to control zones. The actual counting of the electrical appliances used in the office portion of the building and recording the location, category of appliance, and rated power consumption will take place early next quarter.

5.4.2 Interview with Facilities Manager: determine control points

In preparation for DIADR integration, Siemens and LBNL reviewed the as-built capability of the existing APOGEE building management system with the CITRIS'S building facility manager. The DR controllable points are summarized in the table below.

Building parameters used for Demand control		
Building Parameters	*Response*	*Unit*
Current CITRIS building Zone setpoint max and minimum		
Winter Minimum	70 (Local Control from 67-73)	°F
Winter Maximum	70 (Local Control from 67-73)	°F
Summer Minimum	70 (Local Control from 67-73)	°F
Summer Maximum	70 (Local Control from 67-73)	°F
DR Allowed CITRIS building Zone setpoint max and minimum	The allowed limits to use for DR are between 68 and 78	
Winter Minimum	69	°F
Winter Maximum	78	°F
Summer Minimum	69	°F
Summer Maximum	78	°F
DR minimum Precooling setpoint (From midnight to Start of Office Hours)	69	°F
Building operating Hours		
Week day	24	
Holiday	24	
Are there separate Building operating schedules for HVAC for weekday and holiday	CITRIS does not have any occupied/unoccupied schedules, one schedule runs for 24X7	
Are there separate building operating schedules for Lighting for weekday and holiday	7AM-8PM, 2hr override can be done at local	
Are there any Special Zones that are not allowed for DR control	VAV's **not** to be used for DR control include: ○ SDH.S1-01 thru SDH.S1-10 ○ SDH.FCU-1 ○ SDH.CAC-1 ○ SDH.S2-08 ○ SDH.S2-09 ○ SDH.CAC-2 ○ SDH.S3-13 ○ SDH.S3-14 ○ SDH.S4-10 ○ SDH.S4-14 ○ SDH.S4-17	

	○ SDH.S5-15 ○ SDH.S5-17 ○ SDH.S6-09 ○ SDH.S6-14 ○ SDH.S6-16 ○ SDH.S7-11 ○ SDH.S7-12 There are many other points that cannot be used for DR control (example: all points in FAB, chilled water system, etc)	
Accessing Meter data from Apogee using BACnet	By Jan 7 all metered data is available to access. How to access : Link the meter data through Apogee	
Are the following parameters changeable?		Yes/No
Duct static pressure		Yes
Supply Fan Speed		Yes
Supply Air Temperature increase	No big priority, Need to assess required factors in order to use this, otherwise it could cause more energy consumption	
Chilled Water Temperature (Specify chillers that can be used)		No
Switching off hot water valves in winter to the VAV/FCU for some time		Yes
Can some of AHU's turned off, if required?		Yes
Can some of Supply Fans turned off, if required		Maybe
Can some of exhaust fans turned off, if required		Maybe
What chiller used in Summer	Absorption	
What chiller used in Winter	Centrifugal	
RAHU (Recirculation Air Handling Unit)	Only 4 RAHUs are used for CITRIS; the rest are used for Lab and may not be turned off	

Table 1: Controllable points for Demand response.

5.4.3 Whole building modeling

In order to create suitable building models, both LBNL and Siemens needed local weather data for the past two years. UCB provided this data using sMAP, a common interface for all modalities of physical data. Beyond the numerous streams sMAP already provides, four weather stations in and around Berkeley have been added including information on temperature, humidity, wind, precipitation, and other weather parameters over two years.

For simulation of whole building systems, LBNL continued developing a building model in EnergyPlus, using architectural, mechanical and electrical drawings. Modeling effort included the identification of the control zones and development of EnergyPlus zones that map onto the existing BACnet control zones and measurement points. The mapping effort will continue in the next quarter. While the model is being finalized, metering and sub-metering data available from the building were utilized to initiate the calibration of the model. The data available for calibration is limited due to the fact that the data collected over the summer were not stored and that the building loads continued to increase due to the increase in equipment in the building. The results of the plug load inventory effort led by UC Berkeley students, described in 5.4.1, will also be included in the calibration effort when completed. The interview of the facility manager, mentioned in 5.4.2, helped determine both equipment and indoor condition limits for DR strategy development.

UCB, LBNL, and Siemens are exploring a few methods to define a baseline for the project. This information will be valuable later in adding feedback to the total building control. Strategies can be developed and implemented depending on the actual energy consumption real-time and the energy consumption that we are interested in attaining. A program using "fuzzy" logic is being developed to predict with a reasonable amount of accuracy the load expected in a building for a demand response event given no control strategy. This can be viewed as a symbolic baseline to base the power reduction during a demand response event.

5.4.4 Distributed DR control algorithms

UCB is exploring methods how to model the feedback control system on a smaller scale in the laboratory setting with information similar to the submetering data used in Sutardja Dai Hall. The laboratory (Room 464) control zone will be monitored as one of the points and will represent the feedback data to draw from in developing a control strategy.

UCB is working on learning Building Controls Virtual Test Bed (BCVTB) controls to enable Demand Response algorithms at the third party modules to the Smart Energy Box. These third party modules include lighting (WattStopper system) and the distributed load control.

Finally, at the room level, UCB is working on power management of computers, both desktop and laptop machines. The computers are using ACME plugload monitors developed at UC Berkeley, the first version of which had a built-in relay, so they can both control and measure energy consumption. The laptop machines are interesting from a DR perspective because of their onboard energy storage capabilities. We have developed an algorithm using empirically-based laptop battery charging and discharging models that allows preferential charging to the machines that need it most while limiting aggregate overall power consumption. In addition, UCB has engaged Dhaani Systems, a company provides remote administration of Windows computers, particularly in power management. The Dhaani appliance installed in the 3rd floor Sutardja Dai Hall network closet is able to "put to sleep" and "awaken" computers on the network according to inactivity as well as learned schedules, enabling significant power savings. The appliance is currently monitoring only the machines in the DIADR smart office, Room 464, but will soon be expanded to machines across the building.

5.5 Task 06: DIADR local control (Tier3) testing in a lab environment

The test lab, room 464 in Sutardja Dai Hall, is being developed as a smart office laboratory. The focus this quarter was to finalize the list of necessary equipment to test demand response scenarios in a distributed load control environment. The equipment selected to represent typical office equipment includes desktop and laptop computers, a small refrigerator, a laser printer, small fan, and small heater. We chose to supply the computers with power during a demand response event with UPS (Uninterruptible Power Supply) devices capable of supplying power during an entire demand response event. The computers were installed and the programs to be used such as EnergyPlus and BCVTB have been downloaded on the computers for use in analyzing the central load management strategies. We expect to procure and install all equipment in the next quarter.

5.6 Task 8.0—DIADR Building Integration

An additional BACNet server module has been installed by Siemens Building Technology to the APOGEE Building Management System for DR communication. UCB continues to work with Siemens to evaluate the capabilities and limitations of the Siemens APOGEE building management system, toward the goal of a more open data interface. For general research use, we plan to add a SOAP server to the APOGEE system for secured runtime data access next quarter.

WattStopper was invited to participate in the project by assisting with linking the building automation system with the lighting system. A technical representative from WattStopper visited the building to determine how the communication between the two systems can be established. The BACnet interface is being considered for the integration. However, both systems' servers have to be on the same subnetwork. The Apogee server will be moved to the main subnetwork in order to complete this integration.

6 Cost Status

The total budget for the project is listed below:

Total Budget:	**$1,787,674.00**
Salaries/Benefits:	$50,030.75
Subcontract:	$48,418.53
Overhead:	$30,604.08
Total Costs as of 12/31/10:	**$129,053.36**
Balance as of 12/31/10:	**$1,658,620.64**

7 Schedule Status

An updated Project Management Plan was developed and shared with the team members. The Functional Requirements and Architecture Design (Task 2) was completed and a separate document has been created that reports on this development. Task 4 represented a major milestone, and was completed on schedule; the BMS OpenADR Integration was implemented and tested, and is reported in a separate document. All other aspects of the project are on schedule.

8 Changes

The process of taking inventory of the plug loads changed.

9 Anticipated Problems or Delays

There were no anticipated problems or delays.

10 Absences/Changes of Key Personnel

The Project Manager, Gary Baldwin, has been replaced with Therese Peffer. We regret to report the untimely death of Dr. Baldwin; without his effort, this project would not have happened.

There have been no other changes in project personnel.

11 Products of the Project

11.1 A. Publications (list journal name, volume, issue); conference papers; or other public releases of results.

None

11.2 Website with results of this project.

A website is currently in development to host a database to make the scope and results of the project visible to the public. This database will be hosted through the CITRIS website, and will contain a detailed classification of appliances present in common commercial building environments, including model numbers, power ratings for different modes, flexibility, and usage patterns discovered for these devices. The website will also display survey methods, data that has been collected by submeters, and results of from simulations of the DIADR system during DR events.

11.3 Networks or collaborations fostered.

Besides the collaboration among UC Berkeley, Siemens Central Research, and Lawrence Berkeley National Laboratory, the team established communication with WattStopper and Dhaani Systems. WattStopper manufactured the lighting control system in the building, and was invited to participate in the project by assisting with linking the building automation system with the lighting system. A technical representative from WattStopper visited the building to determine how the communication between the two systems can be established. In addition, we have met with the CEO of Dhaani Systems; this company provides remote administration of Windows computers, particularly in power management.

11.4 Technologies/Techniques.

The Siemens Smart Energy Box was developed for this project. A smart phone application was developed for the energy audit.

11.5 Inventions/Patent Applications

None

11.6 Other products, data or databases, physical collections, audio or video, software or netware, models, educational aid or curricula, instruments or equipment.

EnergyPlus model (5.4.3), Rapid Auditing Protocol (5.4.2), Database (11.2)