benefits of using a web-based scheduling optimization service to operate a building with thermal storage and solar-assisted HVAC
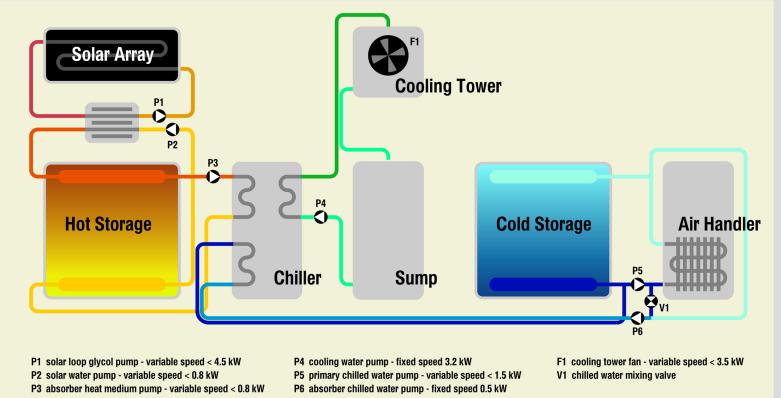
Hans Barsun[1], Richard Burnett[2], Nicholas DeForest[3], Andrea Mammoli[4], Chris Marnay[3], Michael Stadler[3]

1. University of New Mexico Physical Plant Division - Utilities
2. University of New Mexico Physical Plant Division - Engineering Services
3. Lawrence Berkeley National Laboratory - Environmental Energy Technologies Division
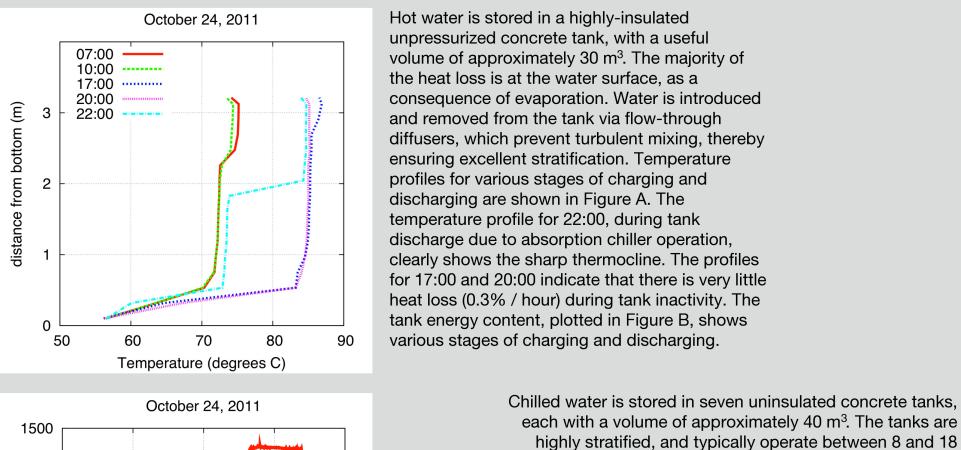4. University of New Mexico Department of Mechanical Engineering & Center for Emerging Energy Technologies

BERKELEY LAB
Lawrence Berkeley National Laboratory

UNM

1: building

P1 solar loop glycol pump - variable speed < 4.5 kW
P2 solar water pump - variable speed < 0.8 kW
P3 absorber heat medium pump - variable speed < 0.8 kW
P4 cooling water pump - fixed speed 3.2 kW
P5 primary chilled water pump - variable speed < 1.5 kW
P6 absorber chilled water pump - fixed speed 0.5 kW
F1 cooling tower fan - variable speed < 3.5 kW
V1 chilled water mixing valve

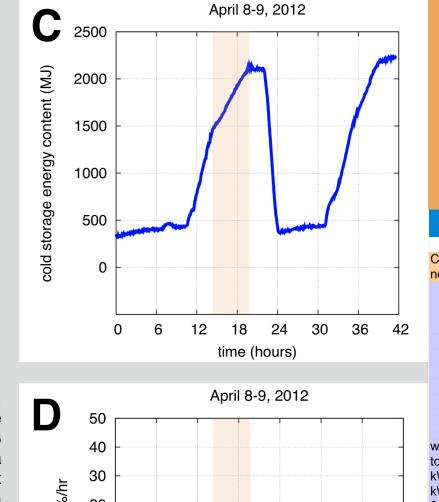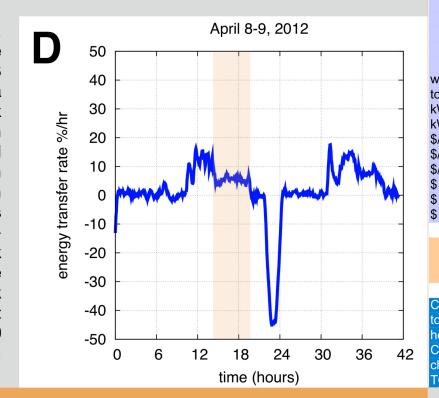The UNM Mechanical Engineering Building is located in Albuquerque, New Mexico USA, a city with arid climate, characterized by cold winter temperatures, moderately high summer temperatures, and monsoon rains typically occurring in the afternoons. The building houses large chilled water storage tanks, which can be charged off-peak via chilled water from the campus district cooling system, and depleted during the day to cool the building. Chilled water is also produced by a solar-powered absorption chiller. Heat medium for the absorption chiller is stored in a hot water tank, that in turn is charged by a rooftop solar array. The solar system produces a volume of hot water which is approximately twice the capacity of the hot water storage tank, so the absorption chiller must run, at least partially, during the solar hot water production period.

The building's HVAC system is managed by a direct digital control (DDC) unit that offers a high level of programming flexibility. The system operation can be either standalone (set schedule adjusted based on real-time system state and measured environmental variables), or externally optimized. In the latter case, a remote agent sets the system schedule so that operating costs, emissions or a combination thereof are minimized. In the present case, the external agent is the Distributed Energy Resource - Customer Adoption Model (DER-CAM).

A — October 24, 2011

Hot water is stored in a highly-insulated unpressurized concrete tank, with a useful volume of approximately 30 m³. The majority of the heat loss is at the water surface, as a consequence of evaporation. Water is introduced and removed from the tank via flow-through diffusers, which prevent turbulent mixing, thereby ensuring excellent stratification. Temperature profiles for various stages of charging and discharging are shown in Figure A. The temperature profile for 22:00, during tank discharge due to absorption chiller operation, clearly shows the sharp thermocline. The profiles for 17:00 and 20:00 indicate that there is very little heat loss (0.3% / hour) during tank inactivity. The tank energy content, plotted in Figure B, shows various stages of charging and discharging.

C — April 8-9, 2012

B — October 24, 2011

Chilled water is stored in seven uninsulated concrete tanks, each with a volume of approximately 40 m³. The tanks are highly stratified, and typically operate between 8 and 18 degrees Celsius. One of the tanks is instrumented with a thermocouple tree, which allows accurate calculation of tank energy content, as shown in Figure C. The tanks begin depleting when the building is occupied and there is a need for chilled water (i.e. if outside air temperature is higher than air handler set point). During chiller operation (shaded bands), the rate of tank discharge is reduced. Rates of energy input (during daytime cooling) and withdrawal (night-time charging) are shown in Figure D for a single tank. Tank discharge begins at approximately 10:30; at 14:20, the absorption chiller begins operating, thereby reducing the tank discharge rate substantially until the end of the cooling day at 19:30. Tank charge begins at 22:00, and continues until 00:30 the next day. Charge loss is approximately 0.06% / hour.
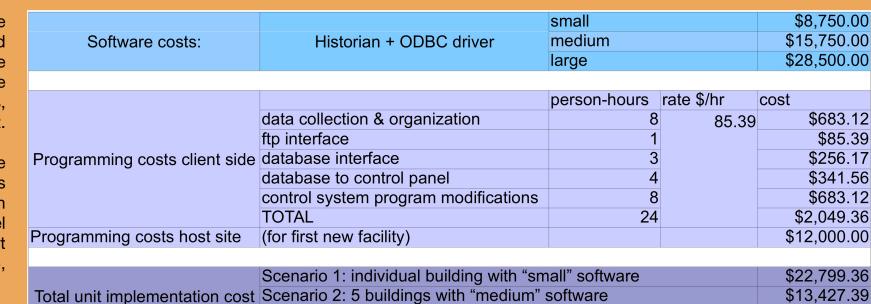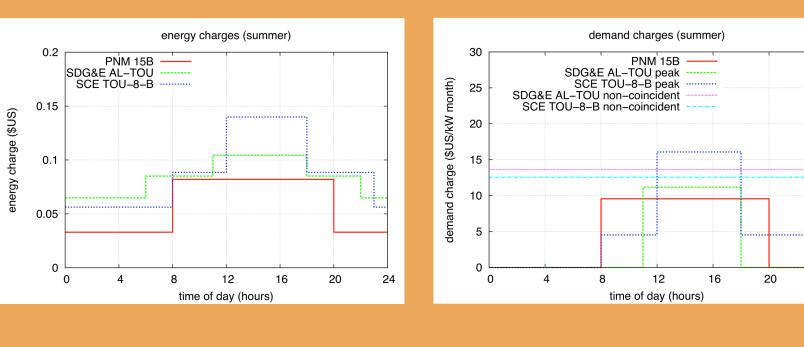

D — April 8-9, 2012

4: economics

The cost of the UNM implementation required a much more substantial effort than indicated here. However, the figures reported are an accurate indication of cost for repeated implementations of the interface. It is also assumed that the basic hardware required for the implementation of the interface and control sequences (servers, programmable controllers) are already present.
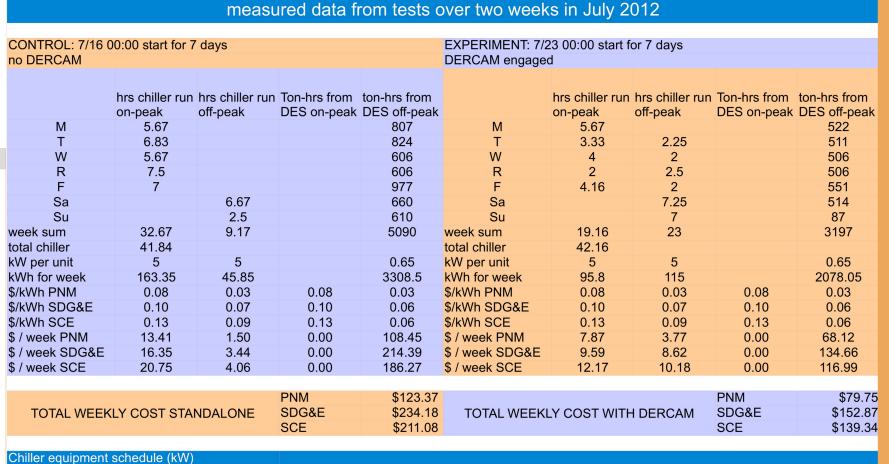
It is apparent that the bulk of the cost is in the data collection software and associated interfaces. These can vary substantially by vendor. It is also apparent that economies of scale apply: for large enterprises with centralized data collection services (e.g. university campuses, hotel chains) costs are substantially reduced. The second largest cost, that associated with reprogramming at the host site (LBNL in this case), can also decrease following an experience curve (85% assumed here).

Software costs:	Historian + ODBC driver	small	$8,750.00
		medium	$15,750.00
		large	$28,500.00

		person-hours	rate $/hr	cost
Programming costs client side	data collection & organization	8	85.39	$683.12
	ftp interface	1		$85.39
	database interface	3		$256.17
	database to control panel	4		$341.56
	control system program modifications	8		$683.12
	TOTAL	24		$2,049.36
Programming costs host site				$12,000.00

Total unit implementation cost	Scenario 1: individual building with "small" software	$22,799.36
	Scenario 2: 5 buildings with "medium" software	$13,427.39
	Scenario 3: 50 buildings with "large" software	$7,414.83

The economic benefits reported below relate to an individual facility, operating in three different environments. One is the actual location in New Mexico, operating under Public Service Company of New Mexico (PNM) rate 15B. The others are rates effective in the San Diego Gas & Electric (SDG&E) and Southern California Edison (SCE) respectively. Only the energy charges were relevant in the present case, since the size of thermal storage could not ensure that the chiller would not operate on-peak during an entire month. However, demand charges would become a factor if many facilities (for example, all 60 DDC buildings on UNM campus) could be aggregated, since in that case coincident peaks could be avoided by the optimization. This would, in the majority of cases, approximately double the economic benefits.

energy charges (summer)

demand charges (summer)

measured data from tests over two weeks in July 2012

CONTROL: 7/16 00:00 start for 7 days no DERCAM	hrs chiller run on-peak	hrs chiller run off-peak	Ton-hrs from DES on-peak	ton-hrs from DES off-peak
M	5.67		807	
T	6.83		824	
W	5.67		606	
R	7.5		606	
F		6.67	377	
Sa		2.5	660	
Su	32.67	9.17	610	
week sum	41.84		5090	
total chiller				
kW per unit			0.65	
kWh for week	163.35	45.85	3308.5	
$/kWh PNM	0.08	0.03	0.08	
$/kWh SDG&E	0.10	0.07	0.10	0.06
$/kWh SCE	0.13	0.09	0.13	0.06
$ / week PNM	13.41	1.50	264.68	
$ / week SDG&E	16.35	3.44	214.39	
$ / week SCE	20.75	4.06	186.27	

EXPERIMENT: 7/23 00:00 start for 7 days DERCAM engaged	hrs chiller run on-peak	hrs chiller run off-peak	Ton-hrs from DES on-peak	ton-hrs from DES off-peak
M	5.67		522	
T	3.33	2.25	511	
W	4	2	506	
R	2	2.5	506	
F	4.16	2	551	
Sa		7.25	514	
Su		7	87	
week sum	19.16	23	3197	
total chiller	42.16			
kW per unit			0.65	
kWh for week	95.8	115	2078.05	
$/kWh PNM	0.08	0.03	0.08	
$/kWh SDG&E	0.10	0.07	0.10	0.06
$/kWh SCE	0.13	0.09	0.13	0.06
$ / week PNM	7.87	3.77	68.12	
$ / week SDG&E	9.59	8.62	134.66	
$ / week SCE	12.17	10.18	116.99	

TOTAL WEEKLY COST STANDALONE	PNM	$123.37
	SDG&E	$234.18
	SCE	$211.08

TOTAL WEEKLY COST WITH DERCAM	PNM	$79.75
	SDG&E	$152.87
	SCE	$139.34

Chiller equipment schedule (kW)	
tower pump	3.2
lower pump	0.8
C/T fan	0.5
chiller solution pump	0.5
TOTAL	5.0

The internalizable savings realized for this experiment support the desirability of utilizing optimized scheduling services for managing distributed energy resources, including thermal storage and load scheduling. In the worst case scenario, that of an individual medium-sized building in a location with low electricity costs (e.g. New Mexico), the payback time is approximately 15 years. With economies of scale, demand charge benefits, and in locations where electricity rate structures encourage customers to manage energy use, the payback time is less than two years.

However, there are also external benefits that are not fully reflected in the internalizable costs for a single facility, but provide substantial value to grid operators when aggregated. These benefits, and their estimated values, include:
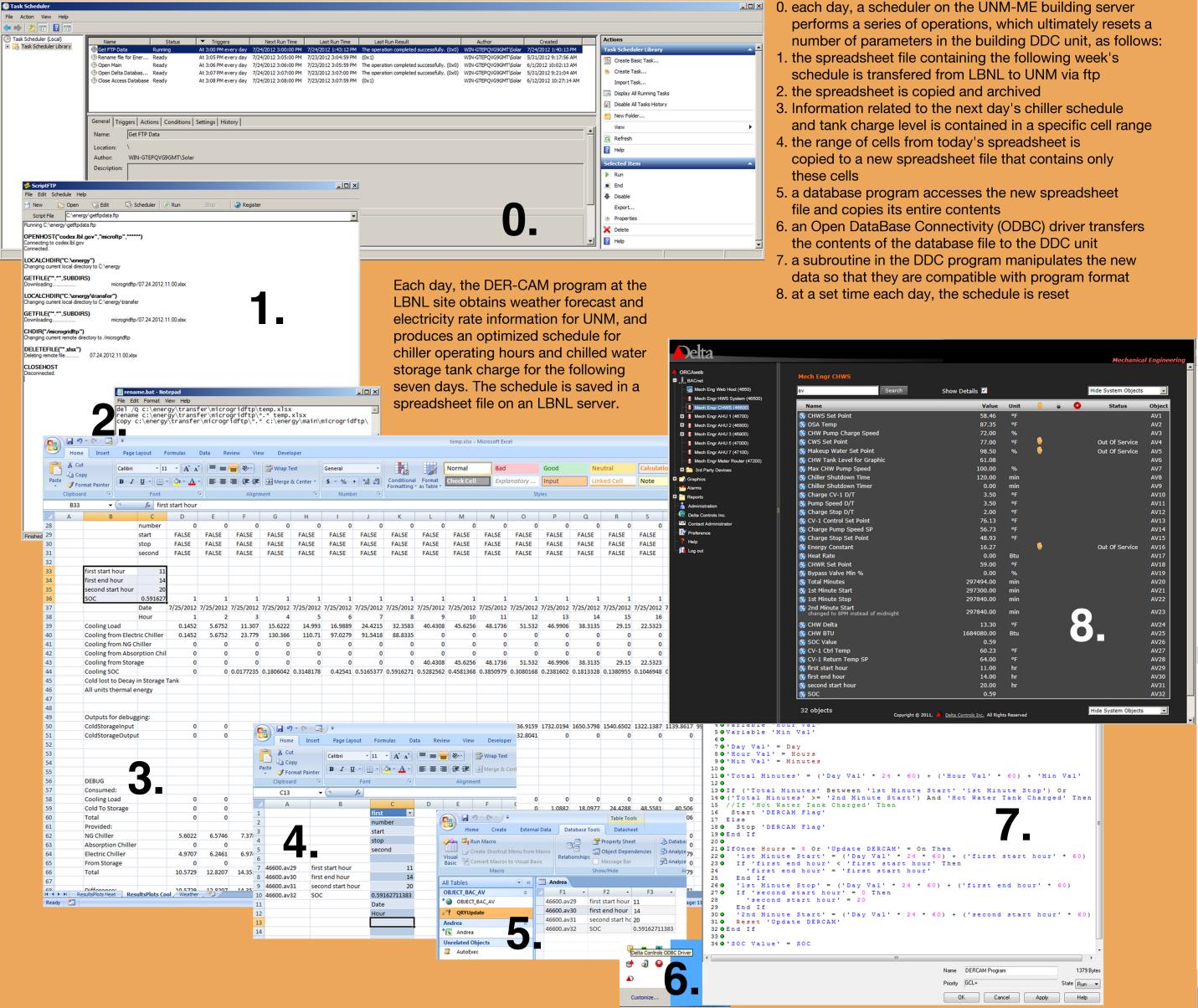
Electric supply capacity - $120/kW-year
Transmission congestion relief - $12/kW-year
Transmission & Distribution upgrade deferral - $420/kW-year
Wind energy time-shift - $32.5/kW-year
Renewables capacity firming - $ 72/kW-year
Avoided Transmission & Distribution energy losses - $8/kW-year

The barriers to internalizing these benefits include the ability to optimize aggregated facilities rather than individual ones, regulatory issues concerning dynamic pricing, limited willingness to adopt software-as-a-service due to lack of familiarity. Even so, external benefits are still realized on a societal basis.
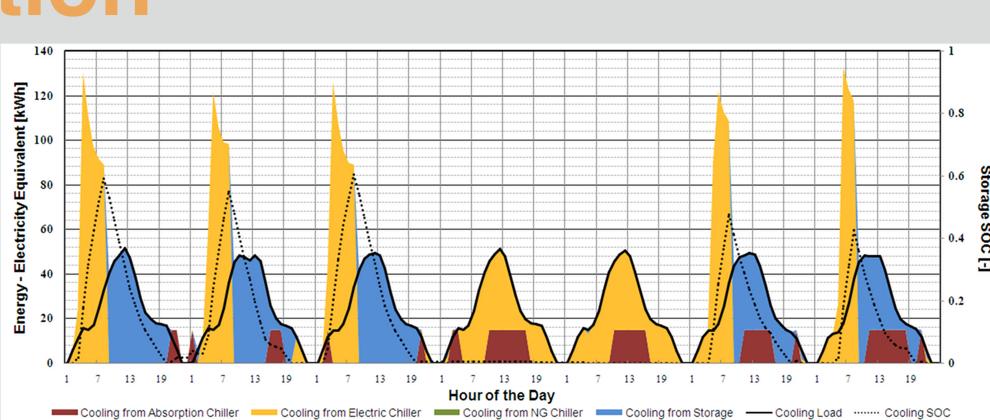
2: interface

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0. each day, a scheduler on the UNM-ME building server performs a series of operations, which ultimately resets a number of parameters in the building DDC unit, as follows:
1. the spreadsheet file containing the following week's schedule is transferred from LBNL to UNM via ftp
2. the spreadsheet is copied and archived
3. Information related to the next day's chiller schedule and tank charge level is contained in a specific cell range
4. the range of cells from today's spreadsheet is copied to a new spreadsheet file that contains only these cells
5. a database program accesses the new spreadsheet file and copies its entire contents
6. an Open DataBase Connectivity (ODBC) driver transfers the contents of the database file to the DDC unit
7. a subroutine in the DDC program manipulates the new data so that they are compatible with program format
8. at a set time each day, the schedule is reset

1.

Each day, the DER-CAM program at the LBNL site obtains weather forecast and electricity rate information for UNM, and produces an optimized schedule for chiller operating hours and chilled water storage tank charge for the following seven days. The schedule is saved in a spreadsheet file on an LBNL server.
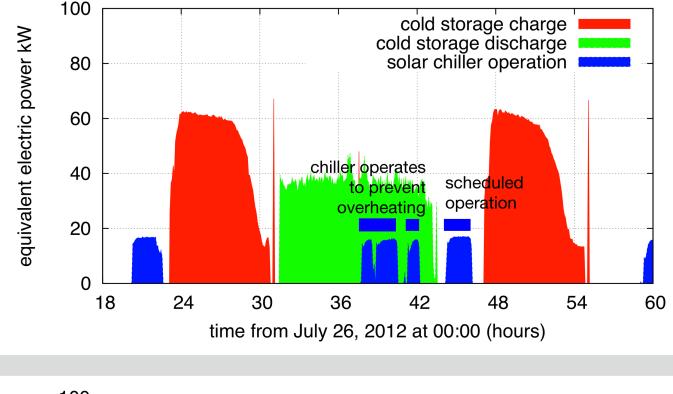

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3: operation

The weekly DER-CAM optimized schedule is produced based on the National Weather Service forecast. The example shown is produces on Tuesday 2012/07/24 for the following week, Wednesday to Tuesday. On weekdays, electrical loads are generally concentrated off-peak (20:00 to 08:00 the following day), while on weekends the cooling load is met in real-time, with no storage. Operation of the electric chiller occurs both on-peak and off-peak, due to the limited capacity of the hot storage tank. However, in the case of cloudy days, when the total daily solar hot water production is lower than the tank capacity, the chiller only operates off-peak (for exampe, day 1 (Wednesday) and day 3 (Friday) in the present example. Although a schedule for an entire week is produced each day, this is replaced every day, so generally only the first day of each weekly schedule is used.
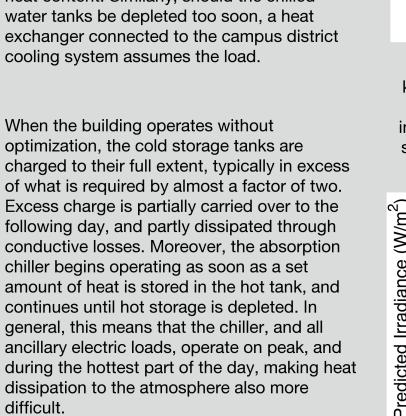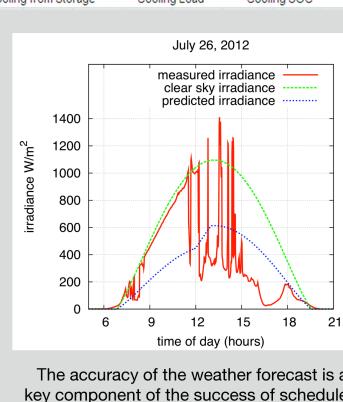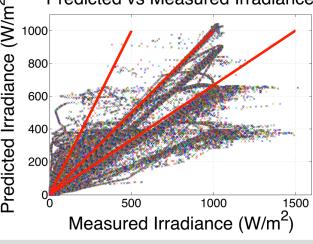

With the DER-CAM scheduling service activated, the cold storage tanks are charged so that they will be able to provide sufficient cooling to the building through the cooling period. Operation of the solar chiller is shifted to the off-peak period, to the extent possible. To prevent damage and discomfort resulting from inaccurate weather and solar forecast, the system has built-in redundancy. For example, when temperature sensors detect incipient hot storage tank overheating, the absorption chiller is activated for one hour, removing approximately one third of the tank heat content. Similarly, should the chilled water tanks be depleted too soon, a heat exchanger connected to the campus district cooling system assumes the load.

July 26, 2012

The accuracy of the weather forecast is a key component of the success of schedule optimization services. Experience so far indicates a bias towards underprediction of solar irradiance. Temperature forecasts, on the other hand, are generally accurate.

chiller operates to prevent overheating — scheduled operation

When the building operates without optimization, the cold storage tanks are charged to their full extent, typically in excess of what is required by almost a factor of two. Excess charge is partially carried over to the following day, and partly dissipated through conductive losses. Moreover, the absorption chiller begins operating as soon as a set amount of heat is stored in the hot tank, and continues until hot water is depleted. In general, this means that the chiller, and all ancillary electric loads, operate on peak, and during the hottest part of the day, making heat dissipation to the atmosphere also more difficult.

Chiller operates in unscheduled mode

Predicted vs Measured Irradiance