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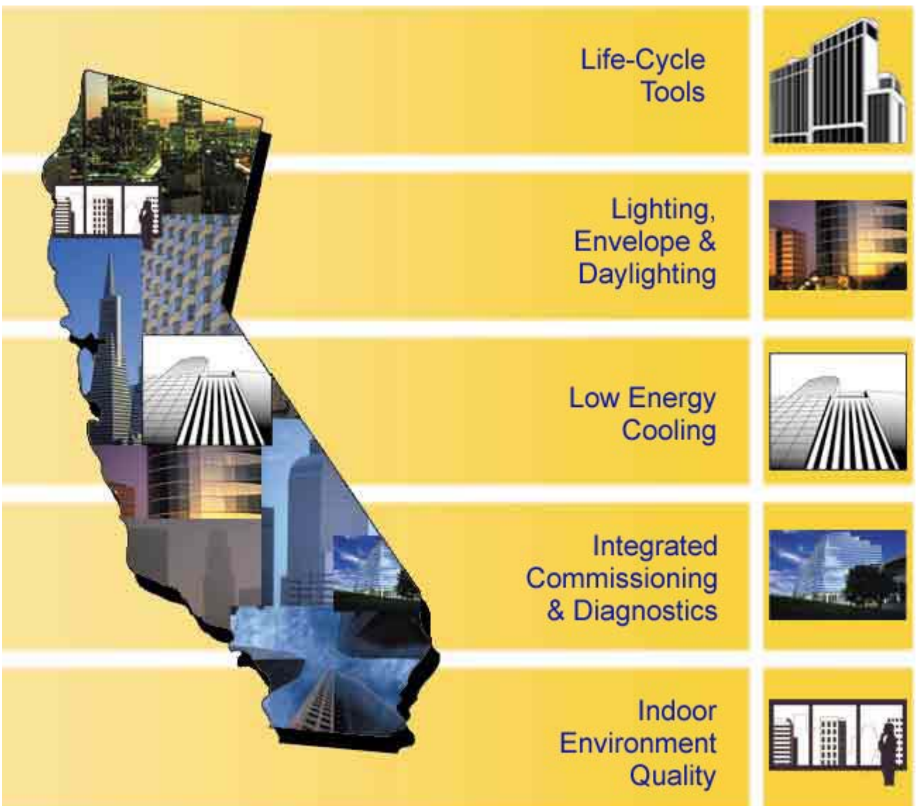
Energy Savings and Cost Benefits For California Relocatable Classrooms



TECHNICAL REPORT

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STATE OF CALIFORNIA
ENERGY COMMISSION

Gray Davis, *Governor*

CALIFORNIA ENERGY COMMISSION

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Program's final report and its attachments are intended to provide a complete record of the objectives, methods, findings and accomplishments of the High Performance Commercial Building Systems (HPCBS) Program. This Commercial Building Energy Benchmarking attachment provides supplemental information to the final report (Commission publication # 500-03-097-A2). The reports, and particularly the attachments, are highly applicable to architects, designers, contractors, building owners and operators, manufacturers, researchers, and the energy efficiency community.

This document is the twenty-first of 22 technical attachments to the final report, and consists of research reports:

- Report on Initial Energy Simulations (E6P2.1T1b)
- Report on Energy Savings Estimates and Cost Benefit Calculations for High Performance Relocatable Classrooms (E6P2.1T2a)

The Buildings Program Area within the Public Interest Energy Research (PIER) Program produced this document as part of a multi-project programmatic contract (#400-99-012). The Buildings Program includes new and existing buildings in both the residential and the nonresidential sectors. The program seeks to decrease building energy use through research that will develop or improve energy-efficient technologies, strategies, tools, and building performance evaluation methods.

For the final report, other attachments or reports produced within this contract, or to obtain more information on the PIER Program, please visit http://www.energy.ca.gov/pier/buildings or contact the Commission's Publications Unit at 916-654-5200. The reports and attachments are also available at the HPCBS website: http://buildings.lbl.gov/hpcbs/.

Abstracts

Report on Initial Energy Simulations

Simulations were completed to compare energy consumption of high performance and typical relocatable classroom designs in four climate zones and two occupancy scenarios using DOE-2. . High performance improvements included:

• Wall insulation R-value increased from R-11 to R-13

• Floor insulation R-value increased from R-11 to R-19

• Grey tint windows replaced with selectively coated glass

• White roof coating added to bare metal roof

• Lighting reduced from 1.66 to 0.75 W/ft²

• SEER 10 wall mount heat pump replaced by two-stage evaporative cooler and variable speed hydronic air handler with wall mount boiler

Simulations were completed for California Climate Zones 4, 11, 12, and 13. Occupancy assumptions corresponding to both traditional and year-round attendance schedules were applied.

Annual source energy savings per classroom for the high performance relocatable classroom averaged 31.3 million Btu per year, or 56% compared to the typical classroom. At fixed electric rates of $0.14 per kWh and natural gas rates of $.60 per therm, annual operating cost savings averaged $502, or 66% compared to the typical classroom. When compared against standard relocatable classrooms operating with the state mandated ventilation rate of 15 CFM/person, average source energy savings and cost savings of the high performance classrooms rise to 68% and $784, respectively.

Non-energy benefits of the high performance relocatable design include reduced noise and improved indoor air quality. Simulation results are being verified by field tests currently in progress. Clearly, the operation schedules employed by the classroom teachers in the field will affect the actual energy usage.

Energy Savings Estimates and Cost Benefit Calculations for High Performance Relocatable Classrooms

This report addresses the results of detailed monitoring completed under Program Element 6 of Lawrence Berkeley National Laboratory's High Performance Commercial Building Systems (HPCBS) PIER program. A key objective of the energy monitoring was to validate DOE2 simulations for comparison to initial DOE2 performance projections. The validated DOE2 model was then used to develop statewide savings projections by modeling base case and high performance RC operation in the 16 California climate zones.

The HPCBS energy efficient RC design is based upon earlier work by Davis Energy Group with Pacific Gas and Electric Company (PG&E), which culminated in the PG&E Premium Efficient Relocatable Classroom (PERC) program (DEG, 1997). The envelope energy efficiency measures selected for the HPCBS project are similar to the PERC Package 1 except the HPCBS package substitutes a white ("Cool Roof") coating for the radiant barrier in the attic space. In addition to the standard wall-mount heat pump system (HPAC), the HPCBS RCs utilize an advanced hybrid system combining an Indirect/Direct Evaporative Cooler (IDEC), which provides two-stage evaporative cooling, and an instantaneous gas-fired heater and a hydronic coil for heating.

Simulations described in this report add upon those conducted previously, with the benefit of data collected during the energy and indoor air and environmental quality (IEQ) field monitoring. Data from the field studies have been used to improve model inputs. The revised DOE2 analyses presented here provide an improved assessment of statewide energy performance for both base case and high performance RCs.

Since the initiation of this project a new revision of the California Title 24 Building Standards has begun (scheduled for release in 2005). As part of this process, RCs were examined and new code enforcement procedures were developed which will result in new RCs having envelope energy features very close to the HPCBS design.

California Energy Commission
Public Interest Energy Research Program

HPCBS #E6P2.1T1b

HPCBS

High Performance Commercial Building Systems

Report on Initial Energy Simulations

Element 6 – Indoor Environmental Quality

Project 2.1 – Energy Simulations and State-Wide Energy Savings

Michael G. Apte and William J. Fisk - Lawrence Berkeley National Laboratory
Leo Rainer - Davis Energy Group, Inc.
January 3, 2002

PIER
Public Interest Energy Research
CALIFORNIA ENERGY COMMISSION

BERKELEY LAB

Report on Initial Energy Simulations.

The report on the following pages, submitted to LBNL under contract by Davis Energy Group, presents the initial DOE-2.1E energy simulations of the "Package B" Relocatable Classroom as defined in the HPCBS Element 6 Scope of Work.

DAVIS ENERGY GROUP
INCORPORATED

HPCBS Element 6, Project 2.1: Relocatable Classroom DOE-2 Analysis Report

Report Issued: January 3, 2002

Presented to: Michael Apte
Lawrence Berkeley National Laboratory

Prepared by: Leo Rainer
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123 C Street
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Executive Summary

Program Element 6 of Lawrence Berkeley National Laboratory's High Performance Commercial Building Systems (HPCBS) PIER program includes a task to complete a DOE-2 evaluation of relocatable classrooms. Simulations were completed to compare energy consumption of high performance and typical relocatable classroom designs in four climate zones and two occupancy scenarios. High performance improvements included:

- Wall insulation R-value increased from R-11 to R-13
- Floor insulation R-value increased from R-11 to R-19
- Grey tint windows replaced with selectively coated glass
- White roof coating added to bare metal roof
- Lighting reduced from 1.66 to 0.75 W/ft²
- SEER 10 wall mount heat pump replaced by two-stage evaporative cooler and variable speed hydronic air handler with wall mount boiler

Simulations were completed for California Climate Zones 4, 11, 12, and 13. Occupancy assumptions corresponding to both traditional and year-round attendance schedules were applied.

Annual source energy savings per classroom for the high performance relocatable classroom averaged 31.3 million Btu per year, or 56% compared to the typical classroom. At fixed electric rates of $0.14 per kWh and natural gas rates of $.60 per therm, annual operating cost savings averaged $502, or 66% compared to the typical classroom. When compared against standard relocatable classrooms operating with the state mandated ventilation rate of 15 CFM/person, average source energy savings and cost savings of the high performance classrooms rise to 68% and $784, respectively.

Non-energy benefits of the high performance relocatable design include reduced noise and improved indoor air quality. Simulation results are being verified by field tests currently in progress. Clearly, the operation schedules employed by the classroom teachers in the field will affect the actual energy usage.

1 Background and Objectives

This report addresses the results of energy performance simulations completed under Program Element 6 of Lawrence Berkeley National Laboratory's High Performance Commercial Building Systems (HPCBS) PIER program. The purpose of the Energy Simulations and Projected State-Wide Energy Savings project is to develop reasonable energy performance and cost models for high performance relocatable classrooms (RC's) across California climates. The objective of the simulation work described in this report is to quantify both energy and dollar savings for the RC packages compared to standard RC construction.

The HPCBS RC energy efficiency implementations are based upon earlier work by Davis Energy Group with Pacific Gas and Electric Co. (PG&E) which culminated in the PG&E Premium Efficient Relocatable Classroom (PERC) program (DEG, 1997). The envelope energy efficiency measures selected for the HPBCS project are similar to the PERC Package 1 with the exception that the roof has a white ("Cool Roof") coating and there is no radiant barrier in the ceiling. In addition to the standard wall-mount heat pump system the HPCBS RC's have an Indirect/Direct Evaporative Cooler (IDEC) which provides heat using a gas-heated hydronic coil.

Simulations described in this report will be repeated in program year 3 after energy and IAQ field studies are completed. The data from the field studies will be used to improve model inputs and assumptions so that the DOE-2 simulations can be refined. The refined simulations will be used to provide improved statewide energy savings and predicted energy usage for both standard and improved RCs.

2 Building Description

School districts purchase RCs either as part of a new school (the state requires 20% of new classrooms to be relocatable in order to be eligible for funding (CA, 1976)), or to provide added class space to existing schools due to population growth or mandated class size reduction (CA, 1999). The majority of RCs in California are either 24' × 40' or 30' × 32' modular structures consisting of two or three modules or "floors" respectively. The modules are factory-built and then trucked individually to the site where they are assembled together. The necessity of highway transportability imposes certain design constraints such as maximum height and width, and structural integrity. Each RC design must be certified by the Division of the State Architect (DSA) for structural integrity and they must meet Title-24 non-residential energy standards (DSA, 1999). However, until recently, RC manufacturers have not had to revise their currently certified DSA plan sets to meet revised Title 24 standards. The RC base case modeled in this report reflect existing DSA plans.

2.1 Envelope

The RCs used in the HPCBS study are a standard 24' × 40' modular classroom consisting of two 12' × 40' rigid steel frame modules connected together along the long axis (see Figure 1). Each classroom has one 4' x 8' metal frame window on each end and a 6'8" x 3' insulated steel door at one end. The walls are framed in wood on 16" centers and covered with T-111 plywood siding on the outside and architectural fabric covered gypsum board on the inside. The roof consists of a single slope of standing-seam roofing on metal purlins with a dropped T-bar ceiling at 8'6" (see Figure 2). The floor is plywood set over metal purlins and covered with carpet. The walls, floor and roof are insulated with fiberglass batts. The floor insulation is covered with a membrane to protect it during transportation and installation. The roof insulation is installed against the underside of the standing-seam roof panels between the metal purlins. The 20” steel perimeter roof beam is not insulated in the base case.

2.2 Lighting

Lighting consists of 12 2’×4’ recessed fluorescent troffers with prismatic lenses set in the ceiling grid and a single fluorescent vapor-jar outside the door. The base case fixtures have 4 T12 lamps with a magnetic ballast while the HPCBS building fixtures have 2 T8 lamps with an electronic ballast and a specular reflector.

2.3 Mechanical

The base case HVAC system consists of a wall-mounted heat pump with two ceiling supply diffusers and a through-the-wall return. The unit is rated at 10 SEER[1] and 6.8 HSPF[2] and has a fixed outside air damper which is set to 15 cfm per person. 10 kW of strip heat is assumed for use during pick-up, defrost, and periods when heat pump capacity is low due to low outdoor temperatures.

The HPCBS cooling system consists of a wall-mounted indirect-direct evaporative cooler (IDEC) with three ceiling supply diffusers and two through-the-wall gravity relief dampers. Heating for the HPCBS RC is provided by a wall-mounted 85% efficient instantaneous gas water heater which supplies hot water to a hydronic heating coil in the supply plenum. 100% outside air is supplied by a variable speed fan which delivers a minimum of 15 cfm per person at all times.

All ducting is run using insulated flex-duct in the plenum space between the T-bar ceiling and the roof, so ducting is within the conditioned space of the building.

[1] Seasonal Energy Efficiency Ratio
[2] Heating Seasonal Performance Factor

Figure 1: RC Plan View

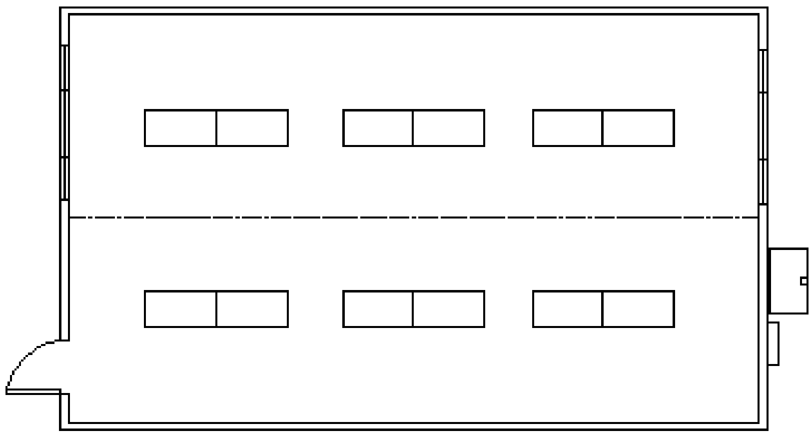
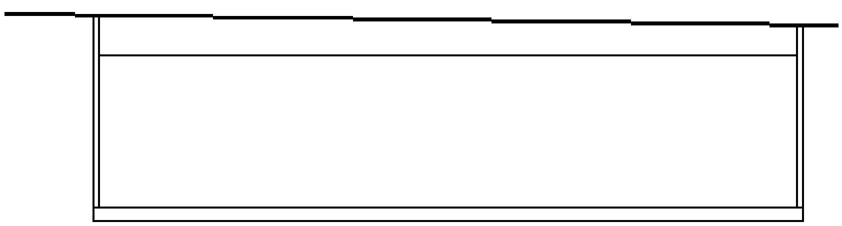


Figure 2: RC Section



3 Simulation Methods

3.1 Analysis Cases

Four different RC envelope / HVAC system configurations were modeled using DOE-2.1E (Buhl, 1993). The base case consisted of the standard envelope with the standard heat pump HVAC system and fan operation set to cycle on with compressor operation (this is presumed to be the operation mode most commonly used in California's RCs). The three comparison configurations were: 1) The standard envelope and heat pump but constant fan operation during occupied hours, which shows the energy impact of constant outside air supplied at 315 CFM, or15 CFM/person as required by law in Title 24 (CCR, 1995). 2) The HPCBS envelope with the standard heat pump and a cycling fan, which shows the effect of the envelope measures alone, when compared to the base case. 3) The HPCBS envelope with the IDEC HVAC system, which shows the effect of the proposed package. Each of the four configurations were simulated in four climate zones with two occupancy schedules, resulting in 32 individual simulations. Climate zones 4 (San Jose), 11 (Red Bluff), 12 (Sacramento), and 13 (Fresno) were selected to represent energy use in the high growth areas of California (CEC, 2001). The two occupancy schedules representing typical year-round and traditional summer vacation schedules are further described below.

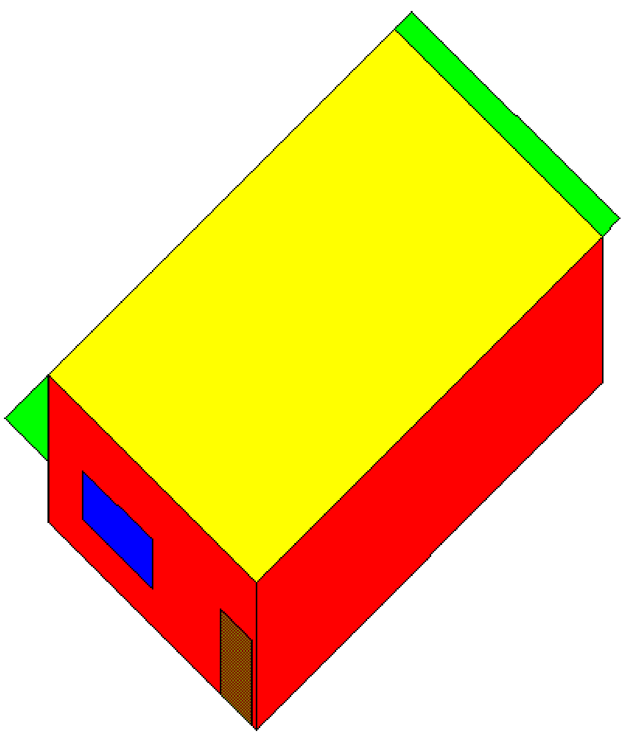
3.2 DOE2 Input File

Structural inputs were taken from working drawings provided by the manufacturer. Performance and operating inputs were developed using a combination of manufactures' data, interviews with school district maintenance personnel, monitored data obtained during previous PG&E RC projects (DEG, 2000), and engineering judgement. A listing of the input file is provided in Appendix A.

Loads

The loads input section is very simple; a graphical view of it is shown in Figure 3. All surfaces were modeled as layered constructions with custom weighting factors except the door which was modeled with a single R-value. The front and back overhangs are modeled as fixed building shades. K-3 occupancy (20 students and one teacher) is assumed with latent and sensible heat gains of 158 and 198 Btu/person respectively (75% of adult male, moderately active office work).

Figure 3: Graphical View of the DOE2 Loads Input



Inputs for the base case and HPCBS classrooms are compared in Table 2. The base case uses the standard insulation and equipment found in the manufacturers usual classroom specification, while the HPCBS classroom uses the PG&E Portable Efficient Relocatable Classroom (PERC) package one specifications plus a white coated roof.

Table 1: Comparison of Base Case and HPCBS Inputs

Input	*Base Case*	*HPCBS*
Wall Insulation R-value	11	13
Floor Insulation R-value	11	19
Roof Insulation R-value	19	19
GLASS-TYPE-CODE	2212 (grey tint)	2660 (selective surface)
Roof ABSORPTANCE	0.60 (bare metal)	0.25 (white coating)
Roof OUTSIDE-EMISS	0.50	0.95
LIGHTING-KW	1.66	0.75

Schedules

Although most schools use traditional schedules, a growing fraction use a year-round schedule; students attend school the same number of days as those on traditional schedules, but they get shorter breaks throughout the year (Chaika, 1999). Because year round operation has significantly more cooling season operation than traditional school schedules, two operating profiles were used for the simulations: year-round and traditional summer vacation. Both provide 180 days of occupancy but the year-round schedule consists of three three-month periods of occupancy separated by one-month breaks while the traditional schedule consists of a conventional school schedule of September though June with two-week breaks in spring and winter and a 2½ month summer vacation (see Figure 4). The weekday occupancy and lighting profiles used are shown in Figure 5. The daily lighting schedule is based on monitoring data from six RC's and includes the effect of bank switching, occupancy changes, and lights left on during non-occupied hours. The occupancy schedule used assumes full occupancy during class time, but both these schedules are expected to be revised based on monitoring data obtained from the HPCBS classrooms.

Figure 4: Annual Profiles for Seasonal and Full Year Operation

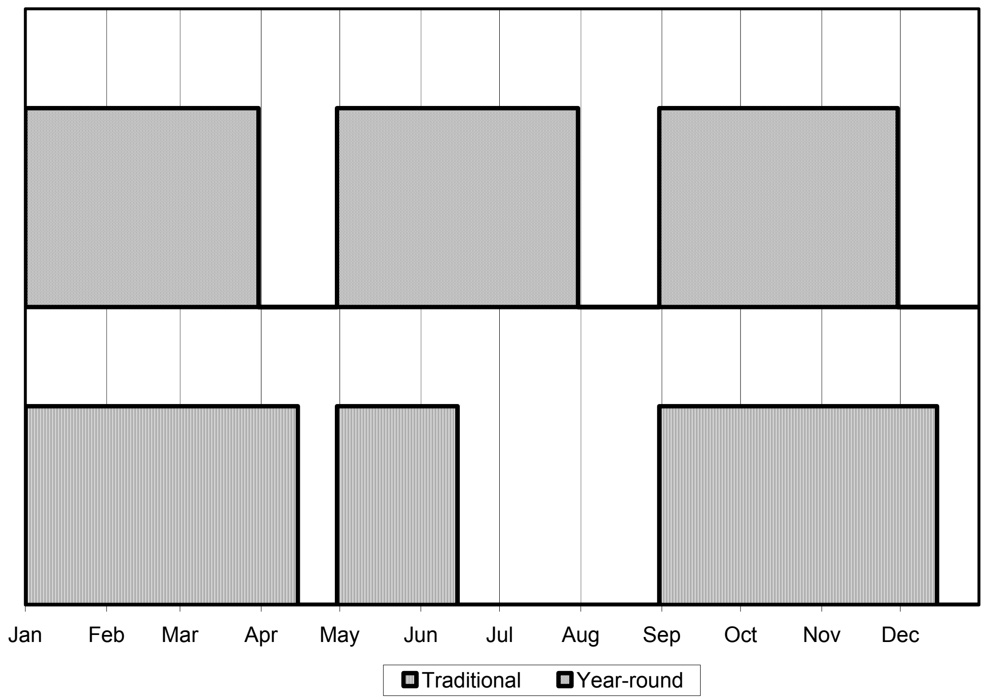
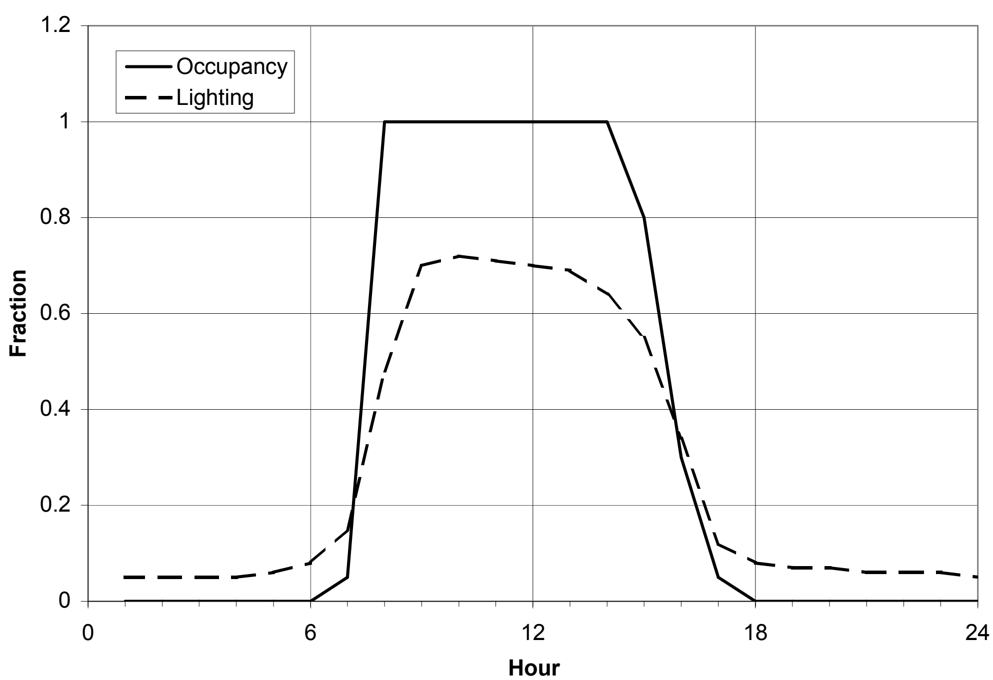


Figure 5: Weekday Profiles for Occupancy and Lighting



Systems

System operating assumptions such as set points, operating hours, and outside air ventilation rates, have the most significant effect on annual energy consumption of any DOE2 inputs and yet are the least well defined. RC HVAC equipment is controlled by a wall mounted thermostat that may have some communication with a central EMCS[3] but is typically set at the discretion of the teacher or custodian. Equipment may or may not be turned off during nights and weekends and setbacks may or may not be implemented. Outside air dampers are rarely set at the correct flow rate and the system fans are typically operated only during compressor operation resulting in no outside air ventilation when cooling or heating demand is satisfied. Finally, door and window use, which affect ventilation, are difficult to define.

Operating schedules and set points were developed using monitored data from six relocatable classrooms. Equipment (heating, cooling, and fans) were assumed to be available weekdays from 8am to 4pm with night operation enabled only if the set points were exceeded. The outside air flow rate was fixed at a total of 315 cfm which corresponds to the ASHRAE 62-99 requirement of 15 cfm/person (ASHRAE, 1999). The heating set point was set at 70°F from 8am to 4pm with a set back to 65°F at night and 60°F on the weekends. The cooling set point was set to a constant 76°F on weekdays and 85°F on weekends.

The inputs used for the base case 10 SEER wall-mount heat pump are summarized in Table 3. Custom efficiency, capacity, and part load curves were developed based on manufactures detailed data for a Bard WH482 (Bard, 2001).

Table 2: Base Case System Inputs

Input	*Value*
SYSTEM-TYPE	PSZ
HEAT-SOURCE	HEAT-PUMP
SUPPLY-FLOW	1400
FAN-CONTROL	CYCLING
SUPPLY-KW/FLOW	0.00032
INDOOR-FAN-MODE	INTERMITTENT
COOLING-CAPACITY	42000
COOLING-EIR	0.349
COOL-SH-CAP	33600
HEATING-EIR	0.4619

[3] Energy Management and Control System

Inputs for the HPCBS system are summarized in Table 3. The DOE2 stand-alone evaporative cooler model was used with the default effectiveness curves (in the next simulation phase detailed IDEC performance data from monitoring will be applied.) Variable fan speed functions are not available with the EVAP-COOL system type, so because fan power is critical to the performance of the IDEC system an external post processing program was used. Hourly output of indoor and outdoor temperatures, and heating and cooling loads were saved for each simulation. Since IDEC fan speed varies in proportion to the load, the fan air flow was adjusted using a linear correlation with heating and cooling part load. Fan air flow rate was calculated as follows:

Heating:

for Heat Load < 35,000 Btuh:

CFM = 315

for Heat Load > 35,000 Btuh:

CFM = 700

Cooling: Assume evaporative effectiveness = 1.0

CoolCap = 1.0 * (Tidb – Towb) * 1.08 * 1600

Where: Tidb = Indoor dry bulb temperature (°F)

Towb = Outdoor wet bulb temperature (°F)

CFM = max(315, CoolLoad/CoolCap * 1600)

Where: CoolLoad = hourly cooling load (Btuh)

315 = minimum air flow rate (cfm)

For ventilation (non-coincident with heating or cooling load), a constant airflow of 315 CFM during occupied hours was assumed. Since a 315 CFM airflow rate is sufficient to meet all heating loads except during morning warmup, winter fan air flow is fairly constant. The 35000 Btuh heating coil capacity corresponds to a 315 CFM airflow rate, and at higher airflows occurring during warmup the coil capacity will be higher and the run time shorter than calculated. The calculation of cooling fan energy use is similarly conservative, since effectiveness typically increases with decreasing airflow. Fan power use was calculated from the fan air flow rate using the following equation which was derived from data monitored during the testing of the IDEC unit at LBNL:

$$\text{Fan Power} = 14.07 * \text{CFM}^{0.000414*\text{CFM}}$$

The instantaneous water heater is modeled as a plant boiler with an HIR of 1.18 (85% efficiency) with no standby or jacket losses.

Table 3: HPCBS System Inputs

Input	*Value*
SYSTEM-TYPE	EVAP-COOL
EVAP-CL-TYPE	INDIRECT-DIRECT
DIRECT-EFF	0.90
INDIR-EFF	0.50
EVAP-CL-KW	0.00005
EVAP-CL+REC-RA	NO
HEATING-CAPACITY	-35000
HEAT-SOURCE	HOT-WATER
SUPPLY-CFM	1600
SUPPLY-KW/FLOW	0.0006
INDOOR-FAN-MODE	CONTINUOUS

4 Simulation Results

Because the base case design is all electric and the HPCBS package uses gas for heating, it is critical to use a well supported method of comparison that weights the gas and electricity use fairly. Two comparisons that lend themselves well to such fuel switching analyses are source energy use and utility costs.

Source energy use provides an indication of what the true total energy impact of an efficiency measure is. However, the conversion factor used to convert electricity into source energy can vary and depends on the aggregate fuel mix and the generation, transmission, and distribution efficiency of the utility providing the electricity. For this analysis we used an average heat rate of 10,239 Btu/kWh, the value used in the California energy efficiency standards, which assumes an aggregate transmission and distribution efficiency of 33% (Fernstrom, et. al., 2000).

Consumer utility costs are easily understood by building owners and equipment purchasers and are required for determining economic payback. However, utility rates have exhibited extreme volatility recently, with schedule G-NR1 natural gas rates varying by more than $1.00 per therm during 2001 and electric rates rising over 20%, making accurate projections of energy cost comparisons problematic. In addition, schools use various electric rate schedules ranging from small schools with simple tiered energy rates to large campuses with time-of-use energy and demand charges. To simplify the analysis we used blended electric and gas rates of $0.14 per kWh and $0.60 per therm to estimate utility costs.

A summary of all 32 runs including total source energy use and annual savings is presented in Table 4. Figure 6 shows a comparison of the source energy use for four different classroom configurations in Sacramento with traditional occupancy. Almost half of the base case building energy use is for lighting, more than one quarter is used for heating, and the remaining quarter is split between cooling and fan energy use.

When the fan is run constantly during occupancy the total energy use rises by 38%, due primarily to the fan energy use which more than triples. Heating and cooling energy use only rise by 25 and 12 percent respectively due to the mild conditions that exist most of the time when the compressor is not running.

When the base case building is upgraded with package 1 measures, lighting energy use is cut by more than half due to the reduction in lighting power density. Heating energy use remains virtually unchanged because the savings due to the better insulation levels is offset by the reduction in heat from the efficient lighting system. The cooling energy use, however, drops by almost half due to the combination of lower lighting power density and reduced glazing and envelope heat gains. Fan energy falls by 30% due to the reduced cooling operation.

Finally, when the base case heat pump is replaced by the IDEC/gas heat HVAC system, source heating energy use drops by 16% and cooling energy use is almost eliminated as the only energy use required by the IDEC in addition to fan energy is cooling pump energy. Fan energy use is cut by 60% due to the high efficiency of the electronically commutated variable speed motor, even though the fan now runs constantly during occupied hours to provide continuous outside air.

Table 4: Summary of DOE2 Simulation Results

					Electric (kWh)					Gas	Total		Annual Savings			
System	Fan	CZ	Schedule	Envelope	Lights	Heating	Cooling	Fans & Pumps	Total	Heating (therms)	Source (Mbtu[a])	Cost	Source (Mbtu[a])	Cost ($)	Energy (%)	Cost (%)
Heat Pump	Cycle	4	Seasonal	Base Case	2311	993	369	257	4009	0	41.0	$561				
Heat Pump	On	4	Seasonal	Base Case	2311	1099	428	1596	5492	0	56.2	$769	-15.2	-$208	-37%	-37%
Heat Pump	Cycle	4	Seasonal	Package 1	1044	984	156	142	2409	0	24.7	$337	16.4	$224	40%	40%
IDEC	On	4	Seasonal	Package 1	1044	51	4	100	1224	80	20.5	$219	20.5	$342	50%	61%
Heat Pump	Cycle	4	Year-round	Base Case	2409	694	598	560	4344	0	44.5	$608				
Heat Pump	On	4	Year-round	Base Case	2409	780	759	1798	5813	0	59.5	$814	-15.0	-$206	-34%	-34%
Heat Pump	Cycle	4	Year-round	Package 1	1088	683	289	505	2650	0	27.1	$371	17.3	$237	39%	39%
IDEC	On	4	Year-round	Package 1	1088	37	6	108	1260	58	18.7	$211	25.8	$397	58%	65%
Heat Pump	Cycle	11	Seasonal	Base Case	2311	1864	752	683	5731	0	58.7	$802				
Heat Pump	On	11	Seasonal	Base Case	2311	2073	984	2678	8132	0	83.3	$1,138	-24.6	-$336	-42%	-42%
Heat Pump	Cycle	11	Seasonal	Package 1	1044	1848	451	371	3838	0	39.3	$537	19.4	$265	33%	33%
IDEC	On	11	Seasonal	Package 1	1044	82	26	148	1326	136	27.2	$267	31.5	$535	54%	67%
Heat Pump	Cycle	11	Year-round	Base Case	2409	1331	1569	1064	6497	0	66.5	$910				
Heat Pump	On	11	Year-round	Base Case	2409	1504	2037	2739	8788	0	90.0	$1,230	-23.5	-$321	-35%	-35%
Heat Pump	Cycle	11	Year-round	Package 1	1088	1322	1092	888	4516	0	46.2	$632	20.3	$277	30%	30%
IDEC	On	11	Year-round	Package 1	1088	59	42	370	1579	100	26.2	$281	40.4	$629	61%	69%
Heat Pump	Cycle	12	Seasonal	Base Case	2311	1382	623	567	4994	0	51.1	$699				
Heat Pump	On	12	Seasonal	Base Case	2311	1552	776	2154	6874	0	70.4	$962	-19.2	-$263	-38%	-38%
Heat Pump	Cycle	12	Seasonal	Package 1	1044	1379	334	349	3220	0	33.0	$451	18.2	$248	36%	36%
IDEC	On	12	Seasonal	Package 1	1044	69	17	157	1314	112	24.7	$251	26.5	$448	52%	64%
Heat Pump	Cycle	12	Year-round	Base Case	2409	993	1165	925	5607	0	57.4	$785				
Heat Pump	On	12	Year-round	Base Case	2409	1129	1493	2327	7453	0	76.3	$1,043	-18.9	-$258	-33%	-33%
Heat Pump	Cycle	12	Year-round	Package 1	1088	988	727	798	3718	0	38.1	$521	19.3	$264	34%	34%
IDEC	On	12	Year-round	Package 1	1088	49	31	316	1505	81	23.5	$259	33.9	$526	59%	67%
Heat Pump	Cycle	13	Seasonal	Base Case	2311	1639	874	724	5659	0	57.9	$792				
Heat Pump	On	13	Seasonal	Base Case	2311	1867	1160	2637	8058	0	82.5	$1,128	-24.6	-$336	-42%	-42%
Heat Pump	Cycle	13	Seasonal	Package 1	1044	1623	498	394	3674	0	37.6	$514	20.3	$278	35%	35%
IDEC	On	13	Seasonal	Package 1	1044	72	28	186	1355	121	26.0	$262	32.0	$530	55%	67%
Heat Pump	Cycle	13	Year-round	Base Case	2409	1079	1698	1078	6379	0	65.3	$893				
Heat Pump	On	13	Year-round	Base Case	2409	1239	2229	2706	8679	0	88.9	$1,215	-23.5	-$322	-36%	-36%
Heat Pump	Cycle	13	Year-round	Package 1	1088	1065	1141	883	4295	0	44.0	$601	21.3	$292	33%	33%
IDEC	On	13	Year-round	Package 1	1088	50	46	407	1610	83	24.8	$275	40.5	$618	62%	69%

[a]Note: for comparison to other energy savings measures, 1 annual Mbtu source energy in a 960 ft^2 RC is equivalent to 1 $Kbtu \cdot ft^{-2} \cdot yr^{-1}$

Figure 6: Source Energy Use Comparison - Climate Zone 12, Traditional Occupancy.

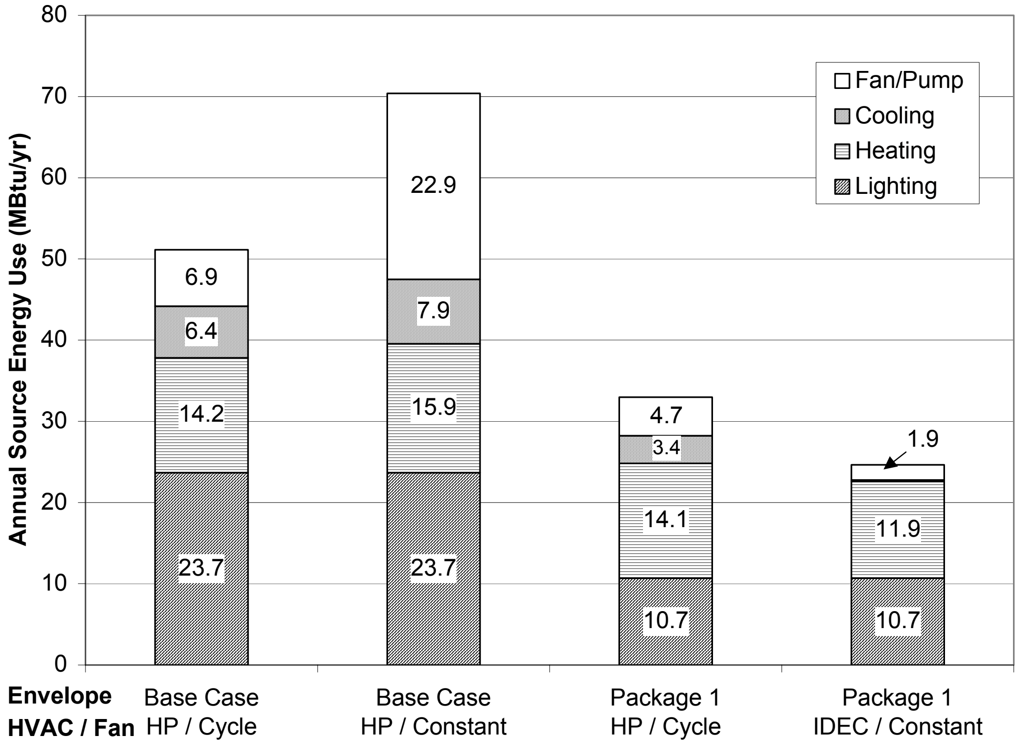


Figure 7 compares annual source energy savings for the HPCBS package vs. a base case envelope with the standard heat pump and a cycling fan in the four climate zones, and for the two operation schedules. Figure 8 similarly compares utility cost savings using the rates stated above.

Annual operating cost savings of from $342 to $535 for traditional occupancy, and from $397 to $629 for year-round occupancy were projected. Savings are the least for climate zone 4 and the greatest for climate zone 11. Clearly, these savings result from a combination of factors, including an improved building envelope, reduced lighting, elimination of compressor energy, fan energy reduction, and more favorable economics of gas heating compared to heat pump heating. Annual maintenance costs, which are likely to be higher for the IDEC system than for the heat pump, would probably degrade these savings by an as yet to be determined amount.

A comparison of operation Configuration 1, where ventilation is provided to the base case RC/HVAC package at 15 CFM/person as legally required, to the HPCBS RC/IDEC package Configuration 3 provides insight into the potential for savings when minimum RC ventilation requirements are met. In this case annual operating cost savings from the HPCBS package range from $550 to $871 for traditional occupancy, and from $603 to $950 for year-round occupancy were projected. Again, savings are the least for climate zone 4 and the greatest for climate zone 11.

Figure 7: Source Energy Savings for HPCBS Package vs. Base Case

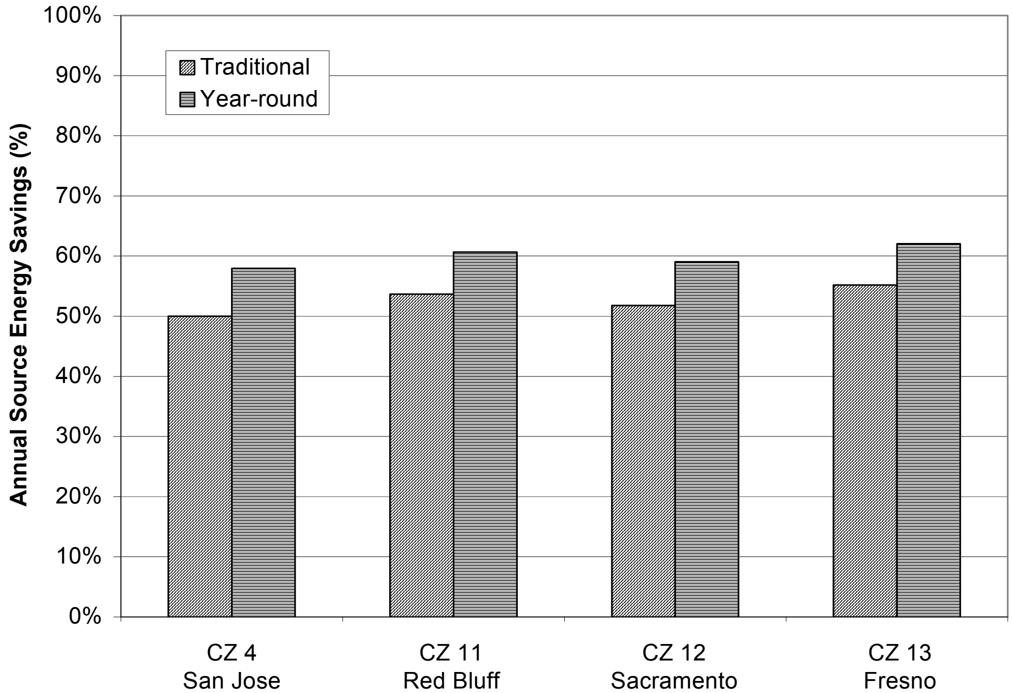
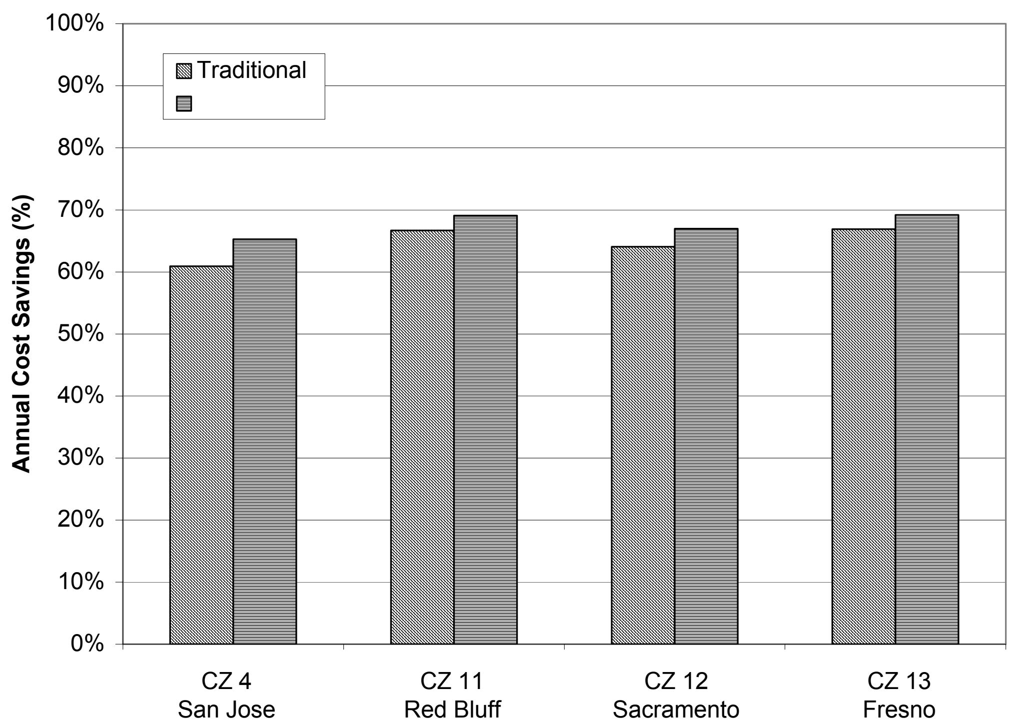


Figure 8: Utility Cost Savings for HPCBS Package vs Base Case



5 Conclusions

Simulations show very significant energy savings for the HPCBS package relative to the base case, suggesting a high probability of a short-term payback, depending of course on the incremental cost of the combined measures. Since envelope improvements are relatively transparent, most HPCBS package issues relate to mechanical systems, and to a lesser extent, lighting. Since the IDEC modeled and installed in the demonstration units is not currently on the market, installed costs and maintenance costs can only be roughly estimated, though field tests may yield useful data. Use of the IDEC could possibly lead to a degradation of comfort or other humidity-related issues resulting from the comparatively higher relative humidity provided from the direct component of the system.

HPCBS benefits that are likely to be recognized from field tests include substantially improved indoor air quality resulting from the 100% outside air heating and cooling air delivery; and reduced noise resulting from elimination of the compressor, lower fan speeds, and reduced heating and cooling demand. Field tests should yield information about occupant acceptability and maintenance requirements, as well as verify energy use and savings projections.

6 References

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Appendix A

DOE2 Input File Listing

```
INPUT LOADS ..

$*********************************************************
$       High Performance Building Systems Task 6
$           24x40 Modular Classroom Building
$         Author: Leo Rainer, Davis Energy Group
$                        2/14/01
$*********************************************************

$ --------------------------------------------------------
$              Macros
$ --------------------------------------------------------
##include ..\run.inc

##if #[shell[] eqs "B"]  $ base case conditions
       ##set1 light  1.66
       ##set1 glass  "2212"     $ grey tint
       ##set1 wallr  "IN11"
       ##set1 floorr "IN11"
       ##set1 absorp 0.6               $ bare standing seam
       ##set1 emiss  0.5
##elseif #[shell[] eqs "1"]  $ PERC package 1 envelope + white roof
       ##set1 light  0.750
       ##set1 glass  "2660"     $ selective surface
       ##set1 wallr  "IN13"     $ R13 wall
       ##set1 floorr "IN12"     $ R19 floor
       ##set1 absorp 0.25       $ white roof
       ##set1 emiss  0.95
##endif

##if #[hvac[] eqs "HP10"]   $ base BARD unit
   ##if #[#[cz[] eqs "CZ11"] OR #[cz[] eqs "CZ13"]]
          ##set1 ccap    56500   $ WH602
              ##set1 shcap   39900
       ##set1 fancfm  1700
   ##elseif #[#[cz[] eqs "CZ12"] OR #[cz[] eqs "CZ02"]]
          ##set1 ccap    47000   $ WH482
              ##set1 shcap   36000
       ##set1 fancfm  1550
       ##else
          ##set1 ccap    41500   $ WH421
              ##set1 shcap   32600
       ##set1 fancfm  1400
       ##endif
       ##set1 hcap    42880
   ##set1 fankw   0.00036
   ##set1 strip   -34000  $ 10kw of strip
   ##set1 ceir    0.325         $ at 95 with fan heat removed
       ##set1 heir       0.305   $ at 47 with fan heat removed
   ##set1 fan cycle    $ default to cycle for now
##elseif #[hvac[] eqs "HP12"] $ 12 SEER wall hung
   ##set1 fankw   0.00019
   ##set1 ceir    0.28
       ##set1 heir       0.37
   ##set1 fan cycle    $ default to cycle for now
##elseif #[hvac[] eqs "IDEC"] $ HPBS idec spec
       ##set1 fan on
##endif

##if #[sched[] eqs "P"]    $ partial year (summer vacation)
       ##set1 occ_sched              OCC-PART
       ##set1 light_sched     LIGHT-PART
       ##set1 heat_sched             HEAT-PART
```

```
        ##set1 cool_sched              COOL-PART
        ##set1 fan_sched               FAN-PART
        ##set1 hvac_sched              ON-PART
##else                                                 $ full year (year round)
        ##set1 occ_sched               OCC-FULL
        ##set1 light_sched     LIGHT-FULL
        ##set1 heat_sched              HEAT-FULL
        ##set1 cool_sched              COOL-FULL
        ##set1 fan_sched               FAN-FULL
        ##set1 hvac_sched              ON-FULL
##endif

##if #[fan[] eqs "cycle"]         $ cycling indoor fan
   ##set1 fan_mode  INTERMITTENT
   ##set1 fan_sched FAN-OFF
        ##set1 econo   FIXED
        ##set1 leak   0.0005
##elseif #[fan[] eqs "on"]        $ indoor fan always on
   ##set1 fan_mode  CONTINUOUS
        ##set1 econo   FIXED
        ##set1 leak   0
##elseif #[fan[] eqs "econo"]  $ economizer
   ##set1 fan_mode  CONTINUOUS
        ##set1 econo   TEMP
        ##set1 leak   0
##endif

##set1 people  21                $ occupants
##set1 osa     315            $ outside air

$ ---------------------------------------------------------
$              Title, Run Periods, Design Days, Holidays
$ ---------------------------------------------------------

TITLE
   LINE-1           = *HPBS 24x40 Modular Classroom*
   LINE-2           = run_title[]
        LINE-3           = cz[]
   ..

ABORT ERRORS  ..
LIST WARNINGS NO-LIMITS              ..
RUN-PERIOD JAN 1 2000 THRU DEC 31 2000      ..
BUILDING-LOCATION
   AZIMUTH   = 270           $  direction front door is facing (W = worst case)
        ..
          LOADS-REPORT
$          VERIFICATION (LV-A,LV-B,LV-C,LV-D,LV-E,LV-F,LV-G,LV-H,LV-I,LV-J,LV-K)
           VERIFICATION (LV-D,LV-F)
           SUMMARY=(LS-E,LS-F)
           HOURLY-DATA-SAVE=FORMATTED ..


$ ---------------------------------------------------------
$              Materials / Layers / Constructions
$ ---------------------------------------------------------


WALLAY = LAYERS
   MATERIAL         = ( PW03, wallr[], GP02)
   INSIDE-FILM-RES=.68
   ..
ROOFLAY = LAYERS
   MATERIAL         = ( AS01, IN03, AL33, AC02)
   INSIDE-FILM-RES=.765
   ..
FLOORLAY = LAYERS
   MATERIAL         = ( floorr[], PW05, CP02)
   INSIDE-FILM-RES=.765
   ..
```

```
WALLCON = CONSTRUCTION
   ABSORPTANCE      = 0.50
   LAYERS           = WALLAY
   ..
ROOFCON = CONSTRUCTION
   ABSORPTANCE      = absorp[]
   LAYERS           = ROOFLAY
   ..
FLOORCON = CONSTRUCTION
   LAYERS           = FLOORLAY
   ..
DOORCON  = CONSTRUCTION  $ solid ureth. door wo/T-B
      U-VALUE=.40 ..

$ ---------------------------------------------------------
$              Glass Types
$ ---------------------------------------------------------

WINDOWCON = GLASS-TYPE
   GLASS-TYPE-CODE  = glass[]
   $FRAME-CONDUCTANCE = FRAMECON
  ..


$ ---------------------------------------------------------
$              Day Schedules
$ ---------------------------------------------------------

OCC-WD = DAY-SCHEDULE
           HOURS = (1,7)      VALUES = (0)
           HOURS = (8)        VALUES = (.05)
           HOURS = (9,14)     VALUES = (1)
           HOURS = (15)       VALUES = (.8)
           HOURS = (16)       VALUES = (.30)
           HOURS = (17)       VALUES = (.05)
           HOURS = (18,24)    VALUES = (0)
   ..
OCC-WE = DAY-SCHEDULE
   (1,24) ( 0 )
   ..
LIGHT-WD = DAY-SCHEDULE
   (1,24) ( 0.05,0.05,0.05,0.05,0.06,0.08,0.15,0.48,0.70,0.72,0.71,
              0.70,0.69,0.64,0.55,0.34,0.12,0.08,0.07,0.07,0.06,0.06,0.06,0.05)
   ..
LIGHT-WE = DAY-SCHEDULE
   (1,24) ( 0.05 )
   ..

$ ---------------------------------------------------------
$              Week Schedules
$ ---------------------------------------------------------

OCC-WEEK = WEEK-SCHEDULE
            DAYS    (WD)         DAY-SCHEDULE = OCC-WD
            DAYS    (WEH)        DAY-SCHEDULE = OCC-WE
   ..

OCC-WEEK-OFF = WEEK-SCHEDULE
            DAYS    (ALL)        DAY-SCHEDULE = OCC-WE
   ..

LIGHT-WEEK = WEEK-SCHEDULE
            DAYS    (WD)         DAY-SCHEDULE = LIGHT-WD
            DAYS    (WEH)        DAY-SCHEDULE = LIGHT-WE
   ..

LIGHT-WEEK-OFF = WEEK-SCHEDULE
            DAYS    (ALL)        DAY-SCHEDULE = LIGHT-WE
   ..

$ ---------------------------------------------------------
```

```
$              Annual Schedules
$ --------------------------------------------------------

LIGHT-PART = SCHEDULE
           THRU APR 30          WEEK-SCHEDULE = LIGHT-WEEK
           THRU MAY 15          WEEK-SCHEDULE = LIGHT-WEEK-OFF
           THRU JUN 15          WEEK-SCHEDULE = LIGHT-WEEK
           THRU AUG 31          WEEK-SCHEDULE = LIGHT-WEEK-OFF
           THRU DEC 15          WEEK-SCHEDULE = LIGHT-WEEK
           THRU DEC 31          WEEK-SCHEDULE = LIGHT-WEEK-OFF
   ..

LIGHT-FULL = SCHEDULE
           THRU MAR 31          WEEK-SCHEDULE = LIGHT-WEEK
           THRU APR 30          WEEK-SCHEDULE = LIGHT-WEEK-OFF
           THRU JUL 31          WEEK-SCHEDULE = LIGHT-WEEK
           THRU AUG 31          WEEK-SCHEDULE = LIGHT-WEEK-OFF
           THRU NOV 30          WEEK-SCHEDULE = LIGHT-WEEK
           THRU DEC 31          WEEK-SCHEDULE = LIGHT-WEEK-OFF
   ..

OCC-PART = SCHEDULE
           THRU APR 30          WEEK-SCHEDULE = OCC-WEEK
           THRU MAY 15          WEEK-SCHEDULE = OCC-WEEK-OFF
           THRU JUN 15          WEEK-SCHEDULE = OCC-WEEK
           THRU AUG 31          WEEK-SCHEDULE = OCC-WEEK-OFF
           THRU DEC 15          WEEK-SCHEDULE = OCC-WEEK
           THRU DEC 31          WEEK-SCHEDULE = OCC-WEEK-OFF
   ..

OCC-FULL = SCHEDULE
           THRU MAR 31          WEEK-SCHEDULE = OCC-WEEK
           THRU APR 30          WEEK-SCHEDULE = OCC-WEEK-OFF
           THRU JUL 31          WEEK-SCHEDULE = OCC-WEEK
           THRU AUG 31          WEEK-SCHEDULE = OCC-WEEK-OFF
           THRU NOV 30          WEEK-SCHEDULE = OCC-WEEK
           THRU DEC 31          WEEK-SCHEDULE = OCC-WEEK-OFF
   ..


$ ********************************************************
$ **                                                    **
$ **      Floors / Spaces / Walls / Windows / Doors      **
$ **                                                    **
$ ********************************************************


CLASSRM = SPACE
       AREA             = 960
   VOLUME           = 11520           $ includes ceiling plenum
   TEMPERATURE      = (74)
   PEOPLE-SCHEDULE  = occ_sched[]
   LIGHTING-SCHEDUL = light_sched[]
   LIGHTING-TYPE    = REC-FLUOR-NV
   PEOPLE-HG-LAT    = 158             $ 75% of Adult male, Moderatly active office work
   PEOPLE-HG-SENS   = 198
   LIGHTING-KW      = light[]
   NUMBER-OF-PEOPLE = people[]
   DAYLIGHTING      = NO
   INF-METHOD       = S-G
   HOR-LEAK-FRAC    = 0.3
   FRAC-LEAK-AREA   = leak[]
   FLOOR-WEIGHT     = 0
   ..

FRONTSH = BUILDING-SHADE
   HEIGHT           = 5
       WIDTH            = 24
       X                = 0
       Y                = 0
       Z                = 12
```

```
        TILT             = 180
        AZIMUTH          = 180
        ..
BACKSH = BUILDING-SHADE
   HEIGHT           = 2
        WIDTH            = 24
        X                = 24
        Y                = 40
        Z                = 12
        TILT             = 180
        AZIMUTH          = 0
        ..
FRONTW = EXTERIOR-WALL
   CONSTRUCTION     = WALLCON
        HEIGHT           = 12
   WIDTH            = 24
        X                = 0
        Y                = 0
        AZIMUTH          = 180
   ..
FWINDOW = WINDOW
   GLASS-TYPE       = WINDOWCON
   X                = 4
   Y                = 3
   HEIGHT           = 4
   WIDTH            = 8
   ..
FDOOR = DOOR
   CONSTRUCTION     = DOORCON
   X                = 20
   HEIGHT           = 7
   WIDTH            = 3.5
   ..

BACKW = EXTERIOR-WALL
   LIKE FRONTW
        X                = 24
        Y                = 40
        AZIMUTH          = 0
   ..
BWINDOW = WINDOW
   GLASS-TYPE       = WINDOWCON
   X                = 4
   Y                = 3
   HEIGHT           = 4
   WIDTH            = 8
   ..

RIGHTW = EXTERIOR-WALL
   CONSTRUCTION     = WALLCON
        HEIGHT           = 12
   WIDTH            = 40
        X                = 24
        Y                = 0
        AZIMUTH          = 90
   ..

LEFTW = EXTERIOR-WALL
   LIKE RIGHTW
        X                = 0
        Y                = 40
        AZIMUTH          = 270
   ..

ROOF-1 = ROOF
   CONSTRUCTION     = ROOFCON
   HEIGHT           = 40
   WIDTH            = 24
        X                = 0
        Y                = 0
        Z                = 12
```

```
        AZIMUTH          = 180
        TILT             = 0
        OUTSIDE-EMISS    = emiss[]
   ..

FLOOR-1 = EXTERIOR-WALL
   CONSTRUCTION     = FLOORCON
   HEIGHT           = 40
   WIDTH            = 24
        X                = 0
   Y                = 40
        Z                = 0
        AZIMUTH          = 180
        TILT             = 180
   ..

END ..

COMPUTE LOADS ..

INPUT SYSTEMS ..

##ifdef func[]
     SUBR-FUNCTIONS
          VARVOL-0=*SETSPEED*
          VARVOL-1Z=*ADDLOAD*
          VARVOL-2=*SAVETEMP*
          VARVOL-3=*SAVELOAD*
          ..
##endif

$ ----------------------------------------------------------
$              Day Schedules
$ ----------------------------------------------------------

COOL-STAT-ON = DAY-SCHEDULE
   (1,24) ( 76 )
   ..
COOL-STAT-OFF = DAY-SCHEDULE
   (1,24) ( 85 )
   ..
FAN-ON-DAY = DAY-SCHEDULE
           HOURS = (1,7)      VALUES = (0)
           HOURS = (8,16)     VALUES = (1)
           HOURS = (17,24)    VALUES = (0)
   ..
FAN-OFF-DAY = DAY-SCHEDULE
   (1,24) ( 0 )
   ..
HEATING-STAT-ON = DAY-SCHEDULE
           HOURS = (1,7)      VALUES = (65)
           HOURS = (8,16)     VALUES = (70)
           HOURS = (17,24)    VALUES = (65)
   ..
HEATING-STAT-OFF = DAY-SCHEDULE
   (1,24) ( 60 )
   ..
ON-DAY = DAY-SCHEDULE
   (1,24) ( 1 )
   ..
OFF-DAY = DAY-SCHEDULE
   (1,24) ( 0 )
   ..

$ ----------------------------------------------------------
$              Week Schedules
$ ----------------------------------------------------------

ON-WEEK = WEEK-SCHEDULE
            DAYS    (ALL)         DAY-SCHEDULE = ON-DAY
        ..
```

```
OFF-WEEK = WEEK-SCHEDULE
            DAYS    (ALL)         DAY-SCHEDULE = OFF-DAY
        ..
FAN-OFF-WEEK = WEEK-SCHEDULE
            DAYS    (ALL)         DAY-SCHEDULE = FAN-OFF-DAY
   ..
FAN-ON-WEEK = WEEK-SCHEDULE
            DAYS    (WD)         DAY-SCHEDULE = FAN-ON-DAY
            DAYS    (WEH)        DAY-SCHEDULE = FAN-OFF-DAY
   ..
HEAT-WINTER-WEEK = WEEK-SCHEDULE
            DAYS    (WD)         DAY-SCHEDULE = HEATING-STAT-ON
            DAYS    (WEH)        DAY-SCHEDULE = HEATING-STAT-OFF
   ..
HEAT-SUMMER-WEEK = WEEK-SCHEDULE
            DAYS    (ALL)         DAY-SCHEDULE = HEATING-STAT-OFF
   ..
HEAT-WEEK-OFF = WEEK-SCHEDULE
            DAYS    (ALL)         DAY-SCHEDULE = HEATING-STAT-OFF
   ..
COOL-SUMMER-WEEK = WEEK-SCHEDULE
            DAYS    (WD)         DAY-SCHEDULE = COOL-STAT-ON
            DAYS    (WEH)        DAY-SCHEDULE = COOL-STAT-OFF
   ..
COOL-WINTER-WEEK = WEEK-SCHEDULE
            DAYS    (ALL)         DAY-SCHEDULE = COOL-STAT-OFF
   ..
COOL-WEEK-OFF = WEEK-SCHEDULE
            DAYS    (ALL)         DAY-SCHEDULE = COOL-STAT-OFF
   ..

$ ---------------------------------------------------------
$              Annual Schedules
$ ---------------------------------------------------------


HEAT-PART = SCHEDULE
           THRU APR 30          WEEK-SCHEDULE = HEAT-WINTER-WEEK
           THRU MAY 15          WEEK-SCHEDULE = HEAT-WEEK-OFF
           THRU JUN 15          WEEK-SCHEDULE = HEAT-SUMMER-WEEK
           THRU AUG 31          WEEK-SCHEDULE = HEAT-WEEK-OFF
           THRU SEP 30          WEEK-SCHEDULE = HEAT-SUMMER-WEEK
           THRU DEC 15          WEEK-SCHEDULE = HEAT-WINTER-WEEK
           THRU DEC 31          WEEK-SCHEDULE = HEAT-WEEK-OFF
                         ..
HEAT-FULL = SCHEDULE
           THRU MAR 31          WEEK-SCHEDULE = HEAT-WINTER-WEEK
           THRU APR 30          WEEK-SCHEDULE = HEAT-WEEK-OFF
           THRU JUL 31          WEEK-SCHEDULE = HEAT-SUMMER-WEEK
           THRU AUG 31          WEEK-SCHEDULE = HEAT-WEEK-OFF
           THRU SEP 30          WEEK-SCHEDULE = HEAT-SUMMER-WEEK
           THRU NOV 30          WEEK-SCHEDULE = HEAT-WINTER-WEEK
           THRU DEC 31          WEEK-SCHEDULE = HEAT-WEEK-OFF
                         ..

COOL-PART = SCHEDULE
           THRU APR 30          WEEK-SCHEDULE = COOL-WINTER-WEEK
           THRU MAY 15          WEEK-SCHEDULE = COOL-WEEK-OFF
           THRU JUN 15          WEEK-SCHEDULE = COOL-SUMMER-WEEK
           THRU AUG 31          WEEK-SCHEDULE = COOL-WEEK-OFF
           THRU SEP 30          WEEK-SCHEDULE = COOL-SUMMER-WEEK
           THRU DEC 15          WEEK-SCHEDULE = COOL-WINTER-WEEK
           THRU DEC 31          WEEK-SCHEDULE = COOL-WEEK-OFF
                         ..
COOL-FULL = SCHEDULE
           THRU MAR 31          WEEK-SCHEDULE = COOL-WINTER-WEEK
           THRU APR 30          WEEK-SCHEDULE = COOL-WEEK-OFF
           THRU JUL 31          WEEK-SCHEDULE = COOL-SUMMER-WEEK
           THRU AUG 31          WEEK-SCHEDULE = COOL-WEEK-OFF
           THRU SEP 30          WEEK-SCHEDULE = COOL-SUMMER-WEEK
           THRU NOV 30          WEEK-SCHEDULE = COOL-WINTER-WEEK
```

```
           THRU DEC 31          WEEK-SCHEDULE = COOL-WEEK-OFF
                         ..

FAN-PART = SCHEDULE
           THRU APR 30          WEEK-SCHEDULE = FAN-ON-WEEK
           THRU MAY 15          WEEK-SCHEDULE = FAN-OFF-WEEK
           THRU JUN 15          WEEK-SCHEDULE = FAN-ON-WEEK
           THRU AUG 31          WEEK-SCHEDULE = FAN-OFF-WEEK
           THRU DEC 15          WEEK-SCHEDULE = FAN-ON-WEEK
           THRU DEC 31          WEEK-SCHEDULE = FAN-OFF-WEEK
                         ..
FAN-FULL = SCHEDULE
           THRU MAR 31          WEEK-SCHEDULE = FAN-ON-WEEK
           THRU APR 30          WEEK-SCHEDULE = FAN-OFF-WEEK
           THRU JUL 31          WEEK-SCHEDULE = FAN-ON-WEEK
           THRU AUG 31          WEEK-SCHEDULE = FAN-OFF-WEEK
           THRU NOV 30          WEEK-SCHEDULE = FAN-ON-WEEK
           THRU DEC 31          WEEK-SCHEDULE = FAN-OFF-WEEK
                         ..
FAN-OFF = SCHEDULE
           THRU DEC 31          WEEK-SCHEDULE = FAN-OFF-WEEK
   ..

ON-PART = SCHEDULE
           THRU JUN 15          WEEK-SCHEDULE = ON-WEEK
           THRU AUG 31          WEEK-SCHEDULE = OFF-WEEK
           THRU DEC 31          WEEK-SCHEDULE = ON-WEEK
   ..
ON-FULL = SCHEDULE
           THRU MAR 31          WEEK-SCHEDULE = ON-WEEK
           THRU APR 30          WEEK-SCHEDULE = OFF-WEEK
           THRU JUL 31          WEEK-SCHEDULE = ON-WEEK
           THRU AUG 31          WEEK-SCHEDULE = OFF-WEEK
           THRU NOV 30          WEEK-SCHEDULE = ON-WEEK
           THRU DEC 31          WEEK-SCHEDULE = OFF-WEEK
   ..
ON-ALL = SCHEDULE
           THRU DEC 31          WEEK-SCHEDULE = ON-WEEK
   ..

$ ********************************************************
$ **                                                    **
$ **               Performance Curves                   **
$ **                                                    **
$ ********************************************************


$ --------------------------------------------------------
$             Curve Fits
$ --------------------------------------------------------

$------------ BARD WH482 -----------
$ Capacity
COOL-CAP-WH48 = CURVE-FIT
   TYPE             = BI-QUADRATIC
   COEFFICIENTS     = (-2.29821768,0.00330886,0.00002091,
                            0.08354232,-0.00027935,-0.00024323)
   ..
$ Sensible Capacity
COOL-SHCAP-WH48 = CURVE-FIT
   TYPE             = BI-QUADRATIC
   COEFFICIENTS     = (-2.37664761,-0.00107246,0.00000543,
                             0.11007952,-0.00078588,-0.00006567)
   ..
$ Efficiency  (from SEER 10)
COOL-EIR-WH48 = CURVE-FIT
   TYPE             = BI-QUADRATIC
   COEFFICIENTS     = (-0.08082241,0.02463397,-0.00019230,
                       -0.00350821,0.00008021,-0.00001524)
..
$ Heating Capacity
```

```
HEAT-CAP-WH48 = CURVE-FIT
   TYPE             = CUBIC
   COEFFICIENTS     = (0.48812796,-0.00214259,0.00040737,-0.00000277)
   ..
$ HEIR
HEAT-EIR-WH48 = CURVE-FIT
   TYPE             = CUBIC
   COEFFICIENTS     = (1.73818534,-0.00900801,-0.00031053,0.00000357)
   ..



$------------ EIR/HIR-FPLR CURVES -----------
$From Danny Parker, FSEC, 1998
$Heat/Cool FPLR for AC cool and HP heat/cool

PLR-EIR-RESYS = CURVE-FIT
   TYPE             = CUBIC
   COEFFICIENTS     = ( 0.0101858, 1.18131, -0.246748, 0.055574)
   ..

PLR-EIR-GHP = CURVE-FIT
   TYPE             = CUBIC
   COEFFICIENTS     = ( 0.00988125, 1.08033, -0.105267, 0.0151403)
   ..

PLR-HIR-RESYS-FR = CURVE-FIT
   TYPE             = CUBIC
   COEFFICIENTS     = ( 0.01177125, 0.98061775, 0.11783017, -0.11032275)
   ..

PLR-HIR-RESYS-FC = CURVE-FIT
   TYPE             = CUBIC
   COEFFICIENTS     = ( 0.00804726, 0.87564457, 0.29249943, -0.17624156)
   ..


"SDL-C20-NEW" = CURVE-FIT
   TYPE             = LINEAR
   COEFFICIENTS     = ( 0.0833, 0.9167 )
   ..

"SDL-C25-NEW" = CURVE-FIT
   TYPE             = BI-QUADRATIC
   COEFFICIENTS     = ( 0.392305, 0.011888, 0, -0.00080916, 0, -2.452e-005 )
   ..

"SDL-C65-NEW" = CURVE-FIT
   TYPE             = LINEAR
   COEFFICIENTS     = ( 0.0833, 0.9167 )
   ..

"GAS-FURN-PLR" = CURVE-FIT
   TYPE             = QUADRATIC
   COEFFICIENTS     = ( 0.018610,1.094209,-0.112819 )
   ..

$ **********************************************************
$ **                                                      **
$ **              HVAC Systems / Zones                    **
$ **                                                      **
$ **********************************************************

CLASSRM = ZONE
   ZONE-TYPE        = CONDITIONED
        DESIGN-HEAT-T    = 70
   DESIGN-COOL-T    = 76
   OUTSIDE-AIR-FLOW = osa[]
   HEAT-TEMP-SCH    = heat_sched[]
   COOL-TEMP-SCH    = cool_sched[]
   ..
```

```
##if #[hvac[] eqs "IDEC"]
SYS-1 = SYSTEM
   SYSTEM-TYPE      = EVAP-COOL
        ZONE-NAMES       =(CLASSRM)
        EVAP-CL-TYPE     = INDIRECT-DIRECT
        DIRECT-EFF       = 0.90                $ CelDek
        INDIR-EFF        = 0.50                $ Adobe HX performance for now
        EVAP-CL-KW       = .00005       $ 80W / 1600cfm pump, single fan
        EVAP-CL+REC-RA   = NO
        HEATING-CAPACITY = -35000       $ hydronic coil
   HEAT-SOURCE      = HOT-WATER
   HEATING-SCHEDULE = hvac_sched[]
   COOLING-SCHEDULE = hvac_sched[]
   SUPPLY-CFM       = 1600
        MIN-OUTSIDE-AIR  = osa[]
   FAN-SCHEDULE     = fan_sched[]
   SUPPLY-KW/FLOW   = 0.0006    $ 1kw/1600cfm
        FAN-CONTROL      = SPEED        $ ECM
        MIN-FAN-RATIO    = 0.1
   NIGHT-CYCLE-CTRL = CYCLE-ON-ANY
   INDOOR-FAN-MODE  = fan_mode[]
   ..
##else
SYS-1 = SYSTEM
   SYSTEM-TYPE      = PSZ
        ZONE-NAMES       =(CLASSRM)
   HEAT-SOURCE      = HEAT-PUMP
   HEATING-SCHEDULE = hvac_sched[]
   COOLING-SCHEDULE = hvac_sched[]
   SUPPLY-FLOW      = fancfm[]
   FAN-SCHEDULE     = fan_sched[]
   FAN-CONTROL      = CYCLING
   SUPPLY-KW/FLOW   = fankw[]
   NIGHT-CYCLE-CTRL = CYCLE-ON-ANY
   INDOOR-FAN-MODE  = fan_mode[]
   COOLING-CAPACITY = ccap[]
   COOLING-EIR      = ceir[]
   COOL-SH-CAP      = shcap[]
        $HEATING-CAPACITY = hcap[]
   HEATING-EIR      = heir[]
        OA-CONTROL       = econo[]
        ECONO-LOCKOUT    = NO
        HEAT-CAP-FT      = HEAT-CAP-WH48
        HEAT-EIR-FT      = HEAT-EIR-WH48
        COOL-CAP-FT      = COOL-CAP-WH48
        COOL-SH-FT       = COOL-SHCAP-WH48
        COOL-EIR-FT      = COOL-EIR-WH48
        COOL-EIR-FPLR    = PLR-EIR-RESYS
        HEAT-EIR-FPLR    = PLR-EIR-RESYS
        HP-SUPP-SOURCE   = ELECTRIC
        HP-SUPP-HT-CAP   = strip[]
        DEFROST-TYPE     = REVERSE-CYCLE
   ..
##endif

PLANT1 = PLANT-ASSIGNMENT
   SYSTEM-NAMES = (SYS-1)
   ..

$ ----------------------------------------------------------
$              Hourly Reporting
$ ----------------------------------------------------------
SYSTEMS-REPORT
          HOURLY-DATA-SAVE=FORMATTED
     VERIFICATION (SV-A)
     SUMMARY=(SS-A,SS-F,SS-H)
          ..

##if #[hvac[] eqs "IDEC"]
BLOCK-1 = REPORT-BLOCK
```

```
   VARIABLE-TYPE    = GLOBAL
   VARIABLE-LIST    = ( 7,8 ) $ WBT, DBT
   ..
BLOCK-2 = REPORT-BLOCK
   VARIABLE-TYPE    = CLASSRM
   VARIABLE-LIST    = ( 6 ) $ TNOW
   ..
BLOCK-3 = REPORT-BLOCK
   VARIABLE-TYPE    = SYS-1
   VARIABLE-LIST    = ( 5,6,33 ) $ heat, cool, fan
   ..


RPT-1 = HOURLY-REPORT
  REPORT-SCHEDULE  = ON-ALL
  REPORT-BLOCK     = ( BLOCK-1, BLOCK-2, BLOCK-3 )
  ..
##endif

END ..

COMPUTE SYSTEMS ..

INPUT PLANT ..

$ Rinnai PLR curve
HW-PLR-RINNAI = CURVE-FIT
   TYPE             = LINEAR
   COEFFICIENTS     = (0.01,1)  $ instantaneous - no degradation
   ..


PLANT1 = PLANT-ASSIGNMENT  ..

          PLANT-REPORT        SUMMARY=(BEPU,PS-B) ..

##if #[hvac[] eqs "IDEC"]
   PLANT-PARAMETERS
          HW-BOILER-HIR       = 1.18
                       E-HW-BOILER-LOSS    = 0
                       HCIRC-DESIGN-T-DROP = 20
                       HCIRC-HEAD          = 24
                       HCIRC-IMPELLER-EFF  = 0.77
                       HCIRC-LOSS          = 0
                       HCIRC-MOTOR-EFF     = 0.7
                       ..

       EQUIPMENT-QUAD
                       HW-BOILER-HIR-FPLR  = HW-PLR-RINNAI
                       ..

   BOILER1         = PLANT-EQUIPMENT
         TYPE             = HW-BOILER
         INSTALLED-NUMBER = 1
         MAX-NUMBER-AVAIL = 1
         SIZE             = 0.04  ..  $ set small now to reduce plr loss (should put in
new curve)

                      PART-LOAD-RATIO
                      TYPE             = HW-BOILER
                      $MIN-RATIO        = 0
                      MAX-RATIO        = 1
                      ELEC-INPUT-RATIO = 0.007      $ 80W/40KBTU
                      ..
##endif

END ..
COMPUTE PLANT ..

STOP ..
```

California Energy Commission
Public Interest Energy Research Program

HPCBS # E6P21T2a

HPCBS

High Performance Commercial Building Systems

Energy Savings Estimates and Cost Benefit Calculations for High Performance Relocatable Classrooms **DRAFT**

Element 6 - Indoor Environmental Quality
Project 2.1 - Energy Simulations & State-wide Energy Savings

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Davis Energy Group, Inc.

July, 2003

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DAVIS ENERGY GROUP
INCORPORATED

HPCBS Element 6, Project 2.1.2: Energy Savings Estimates and Cost Benefit Calculations for High Performance Relocatable Classrooms

DRAFT

Report Issued: July 16, 2003

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Executive Summary

Program Element 6 of The High Performance Commercial Building Systems (HPCBS) project involves both modeling and monitoring of the performance and cost-effectiveness of high performance relocatable classrooms (RCs). During typical years roughly 4,000 RCs are installed in California, although recent class size reduction efforts have increased annual production to close to 10,000 units. Cost-effective improvements in RC energy efficiency and indoor air and environmental quality (IEQ) have the potential to create a healthier and more productive learning environment for K-12 students in California.

A high performance RC "package" featuring improved envelope components, high efficiency lighting, and an advanced hybrid HVAC system was installed in four RCs. Conventional 6.8 HSPF/10 SEER wall-mount heat pumps (HPAC) were installed in parallel so the systems could be switched on a weekly basis, allowing each classroom to act as its own control. The advanced hybrid system features a variable speed two-stage indirect-direct evaporative cooler (IDEC) combined with an instantaneous gas water heater and pump which supply hot water to a hydronic coil. The advanced hybrid system also provides minimum outdoor air ventilation (15 cfm/person) during occupied hours. Although continuous ventilation is beneficial from an indoor air quality perspective, the higher ventilation rate increases space conditioning loads. The challenge of this project is to demonstrate IEQ improvements can be obtained without sacrificing energy efficiency.

Two RCs with dual HVAC systems each were installed at schools in Modesto and Cupertino, California, and monitored from September 2001 to June 2002. Detailed data on energy use, air temperatures, relative humidities, and system operation were collected on six-minute intervals. Data for occupied days were analyzed and regression relationships were developed to characterize daily electrical and gas consumption as a function of average daily outdoor temperature. A DOE2 building simulation model was validated using the monitoring from the two RCs at each site. Base case HVAC performance was found to be considerably poorer than the expected nominal HSPF and SEER for the wall-mount HPAC's. Full season heating and cooling performance was approximately 30% less efficient than the nominal HPAC seasonal values, primarily due to thermostat control issues and typically short run cycles.

The validated model was used to generate performance projections in all 16 California climate zones for both advanced hybrid systems and high efficiency HPACs (6.8 HSPF, 12 SEER). Continuous minimum outdoor air (21 occupants with 15 cfm/person) was modeled in both cases to ensure consistency between the simulated loads. Operating costs were tabulated based on statewide average blended commercial rates of $0.147 per kWh and natural gas rates of $0.74 per therm. Based on the assumed statewide distribution of RCs, the following "per unit" weighted average impacts were determined:

- 1,494 kWh saved (82% reduction)
- 5.9 kW winter peak electric load reduction (96% reduction)
- 3.3 kW summer peak electric load reduction (72% reduction)
- 26 therm gas increase

- 13 Mbtu source energy savings (69% reduction)
- $220 annual operating cost savings, ranging from $159 to $385 (82% reduction)

The statewide technical potential based on converting 4,000 new RCs to advanced hybrid systems is projected to:

- save 5,975 MWh of electricity per year
- reduce winter peak electric load by 23.8 MW
- reduce summer peak electric load by 13.1 MW
- increase natural gas consumption by 1025 Mbtu per year
- reduce source energy use by 50,931 Mbtu per year
- reduce school district annual operating costs by $880,900

Advanced hybrid incremental cost estimates were developed based on the key system components. The IDEC and the instantaneous water heater are the most costly components of the $2,400 advanced hybrid system. The advanced hybrid incremental hardware cost of $1,586 is further increased by $200 to $1000 per unit based on the cost of connecting to an available properly sized gas line at the site. Although high heating load applications, such as climate zone 16, demonstrate simple paybacks as favorable as 4.6 years, the statewide average payback for the advanced RC is estimated at 9.9 years.

Advanced hybrid HVAC systems offer an efficient alternative to conventional HPACs. In addition to efficient space conditioning, advanced hybrid HVAC systems offer continuous high efficiency outdoor air ventilation. Unfortunately, the advanced hybrid technology evaluated in this study is not currently available as a packaged system. If a market develops for the advanced hybrid technology, competing products should appear and costs should decrease.

Although the advanced hybrid system offers significant energy efficiency benefits, there are issues to first address. The IDEC system requires more frequent maintenance than a standard HPAC. Evaporative media needs to be replaced, typically on 3-5 year intervals, and teachers and service personnel needs to be trained on the operational characteristics and maintenance requirements of the system. In addition, the IDEC will be hard-pressed to provide comfort in the extreme desert regions of California where mid-summer temperatures frequently exceed 110ºF and in year-round schools in the inland valley regions.

The advanced hybrid system offers great potential for improving the energy efficiency of RCs, while also improving IEQ. A larger scale field test of advanced hybrid systems would provide more data on system performance, installed costs, and teacher/staff satisfaction.

1 Background

This report addresses the results of detailed monitoring completed under Program Element 6 of Lawrence Berkeley National Laboratory's High Performance Commercial Building Systems (HPCBS) PIER program. The purpose of the Energy Simulations and Projected State-Wide Energy Savings project is to develop reasonable energy performance and cost models for high performance relocatable classrooms (RCs) across California climates. A key objective of the energy monitoring was to validate DOE2 simulations for comparison to initial DOE2 performance projections. The validated DOE2 model was then used to develop statewide savings projections by modeling base case and high performance RC operation in the 16 California climate zones.

The HPCBS energy efficient RC design is based upon earlier work by Davis Energy Group with Pacific Gas and Electric Company (PG&E), which culminated in the PG&E Premium Efficient Relocatable Classroom (PERC) program (DEG, 1997). The envelope energy efficiency measures selected for the HPCBS project are similar to the PERC Package 1 except the HPCBS package substitutes a white ("Cool Roof") coating for the radiant barrier in the attic space. In addition to the standard wall-mount heat pump system (HPAC), the HPCBS RCs utilize an advanced hybrid system combining an Indirect/Direct Evaporative Cooler (IDEC), which provides two-stage evaporative cooling, and an instantaneous gas-fired heater and a hydronic coil for heating.

Simulations described in this report add upon those conducted in program year 1, with the benefit of data collected during the energy and indoor air and environmental quality (IEQ) field monitoring. Data from the field studies have been used to improve model inputs. The revised DOE2 analyses presented here provide an improved assessment of statewide energy performance for both base case and high performance RCs.

Since the initiation of this project a new revision of the California Title 24 Building Standards has begun (scheduled for release in 2005). As part of this process, RCs were examined and new code enforcement procedures were developed which will result in new RCs having envelope energy features very close to the HPCBS design. Table 1 summarizes key energy features of the HPCBS RC package. Additional background information on the construction details and assumed operating characteristics of RCs, as well as full-year DOE2 performance projections, can be found in the 2001 project report entitled Relocatable Classroom DOE2 Analysis Report, (Apte et al, 2001), and (Shendell et al, 2002).

Table 1: HPCBS Envelope Inputs

Parameter	*Value*
Wall Insulation R-value	13
Floor Insulation R-value	19
Roof Insulation R-value	19
Glazing U-Value	0.48
Glazing Tvis	0.66
Glazing SHGC	0.49
Roof Absorptance	0.25 (white coating)
Roof Emissivity	0.95
Lighting Intensity	0.75 W/ft^2

2 Objectives

The primary objective of this phase of work was to utilize detailed field monitoring data to modify DOE2 inputs and generate performance projections based on a validated simulation model.

Additional objectives include the following:

1. Obtain comparative performance data on base case and high performance HVAC systems to determine how they are operated, how they perform, and how the occupants respond to the advanced systems. This was accomplished by installing both HVAC systems side-by-side (i.e., one per module of a standard two module, 24' by 40' RC) on the study RCs and switching HVAC operating modes on a weekly basis.

2. Develop projected statewide energy and demand impacts based on the validated DOE2 model.

3. Develop cost effectiveness projections for the high performance HVAC system in the 16 California climate zones.

3 Methodology

3.1 Overview

To accurately determine performance of the HPCBS HVAC system relative to the base case HPAC unit, a total of four RCs were tested in two locations (Modesto and Cupertino). Modesto is located in the Central Valley approximately 80 miles south of Sacramento, and Cupertino is located roughly 40 miles southeast of San Francisco. The climates are distinct, especially in the summer when Modesto experiences hotter, drier weather than Cupertino, which is moderated by its proximity to the Pacific Ocean. Table 2 summarizes ASHRAE design data for the two locations (ASHRAE 1982).

Table 2: Monitoring Site Design Weather Conditions

ASHRAE Design Condition	Cupertino	Modesto
Summer design dry bulb (0.5%*)	88ºF	99ºF
Coincident wet bulb	67ºF	70ºF
Summer daily temperature range	30ºF	30ºF
Winter design dry bulb (0.2%*)	33ºF	30ºF

* percentage values refer to the fraction of the year that these values are expected to be exceeded (0.5% = 44 hours, 0.2% = 18 hours).

The RCs at each site were used as standard elementary school classrooms, with Cupertino having about thirty 4th graders and Modesto having about twenty 3rd graders in each RC at full enrollment. Typical HVAC system operating hours were 8 AM to 3 PM (Modesto) and 8 or 9 AM to 4 PM (Cupertino). Normal day-to-day variations in operation occurred which caused some of the data to be excluded during data analyses. Monitoring of system performance occurred from September 2001 to June 2002. .

3.2 Description of HVAC Systems

Each of the RCs had two HVAC systems: a conventional wall-mount heat pump (HPAC) and an advanced hybrid HVAC system consisting of a two-stage evaporative cooler and a hydronic fan coil (advanced hybrid).

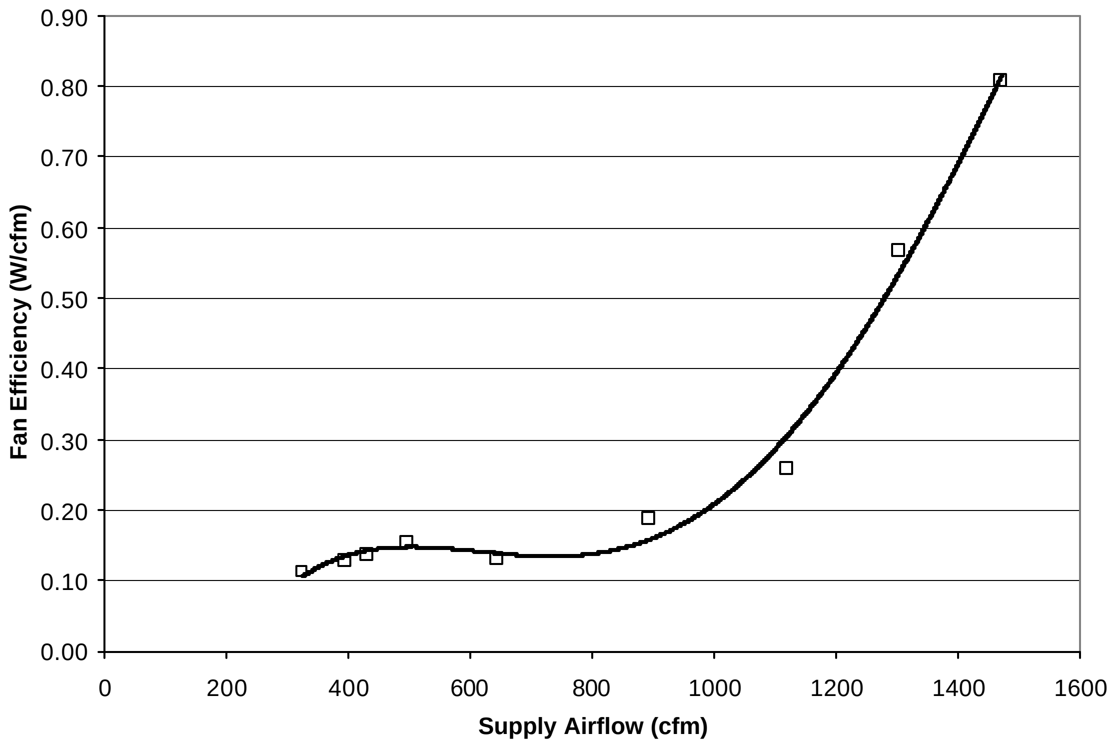
The conventional HPAC system was a standard 3.5 ton heat pump rated at 10 SEER and 6.8 HSPF with 10 kW of electric strip heat. Fan airflow was rated at 1400 CFM delivered through two 14” flex supply ducts. Outside air was provided by two ventilation options: at Modesto the HPAC used a barometric air damper which can deliver up to 25% outside air. At Cupertino, due to the larger outside air load, a motorized damper was installed which can supply up to 50% outside air. Both districts used a commercial heating/cooling (non-heat pump) thermostat to operate the HPAC system. In addition, Cupertino added a four hour lock-out timer, which prevents the HPAC system from operating more than four hours after occupancy ends.

The advanced hybrid system consists of a two-stage evaporative cooler (IDEC) with a variable speed electronically commutated motor (ECM) capable of delivering 1500 CFM of air through three 12” flex ducts. Three high performance filters (Koch Filter Corporation, Louisville, KY) provided 65% ASHRAE Dust Spot Efficiency filtering of air. Heating was provided by a hydronic hot water coil sized to deliver 40,000 Btu at an entering air temperature of 32ºF at 750 cfm airflow. The 32ºF design temperature was selected since the system is always operating in 100% outdoor air mode to promote improved IEQ . Heat to the hydronic coil was provided by a pilotless (intermittent ignition device) 82% recovery efficiency instantaneous gas water heater[1].

[1] The 180,000 Btu/hour input unit has variable heating capacity ranging from 19,000 to 180,000.

The ECM motor operates efficiently at low airflow, making it an attractive choice as a supply air fan motor for the RC application, where much of the operation is at minimum outdoor airflow rates. The efficiency of delivering air (expressed in terms of Watts/cfm) increases by a factor of five between full-speed operation and operation at typical outside air flow rates. Figure 1 plots monitored IDEC airflow delivery efficiency characteristics taken during testing.

Figure 1: IDEC Fan Efficiency vs. Supply Airflow



The advanced hybrid control is a modified version of the standard IDEC control. It has three lights which indicate the mode (heat, cool, and auto), a single temperature slider, and a push button for selecting the mode. In heating mode, the supply fan operates at low speed to deliver the minimum outside air volume required. When the measured indoor air temperature drops below the set point, the hydronic pump is turned on and the water heater fires to maintain 160°F water supplied to the coil. If the indoor air temperature drops to more than 3°F below the set point the airflow is increased to 700 cfm to provide additional heating capacity. In cooling mode, the supply fan also operates at low speed to deliver the minimum outside air volume required. When the indoor air temperature rises above the set point, the IDEC pump is turned on to wet the direct and indirect media and then airflow is set proportional to the difference between the indoor air temperature and the thermostat set point. If the teacher chooses a low temperature setting on the IDEC thermostat, the ECM motor will run at maximum speed to try to achieve the setpoint.

Table 3 summarizes key operating characteristics of the base case HPAC system and the advanced hybrid system.

Table 3 HVAC System Operating Characteristics

	HPAC	Advanced Hybrid
Minimum outdoor air	Only when compressor on	Constant at 15 cfm/person
Heating mode operation	Compressor and fan "on," strip heat if needed	Maintain minimum outdoor air; activate pump and heater; increase cfm if unable to maintain setpoint (100% outdoor air)
Cooling mode operation	Compressor and fan "on"	Operates in fully variable speed mode in response to "indoor air to thermostat" temperature difference (100% outdoor air)

3.3 Data Analysis Methodology

A key goal in analyzing the monitoring data was to collect schedule data for the DOE2 validation work and to characterize HVAC system performance in terms of daily energy consumption as a function of daily average outdoor dry bulb temperature.

System operating assumptions such as thermostat setpoints, operating hours, and outside air ventilation rateshave a significant effect on annual energy consumption, and yet little reliable data had been collected. Although school districts frequently have guidelines on thermostat settings and schedules, actual thermostat control is often at the discretion of the teacher or custodian. Equipment may or may not be turned off during nights and weekends. Outside air dampers may not be set at the correct flow rate, and the system fans are typically operated only during thermal space conditioning,resulting in no outside air ventilation when cooling or heating demand is satisfied. Finally, door and window use, which affect ventilation, are difficult to define.

A subset of the IEQ monitoring data collected in this project was utilized in evaluating HVAC system performance. Temperature, relative humidity, power, gas use, and component status data were collected on six-minute intervals for each classroom; door and window opening data were also collected, but not used for this analysis. Prior to data analysis, three data cleaning and calculation steps were performed:

- Raw data were reviewed and bad data points were removed or corrected. Problems were encountered with digital data during the monitoring project start-up and sporadically during the monitoring. This resulted in some blocks of power and gas data being discarded.
- Fields not necessary for energy analysis were discarded.
- Six-minute data were aggregated into hourly and daily files. These were then combined into seasonal files with one file for each classroom.

With the monitoring approach of alternating HVAC system operation on a weekly basis, data were collected during fairly comparable weather patterns. Daily energy use totals were plotted against daily average outdoor air temperature. For the HPAC units, daily electrical energy use was plotted; for the advanced hybrid system, both electrical energy use and gas consumption were plotted. Although advanced hybrid continuous fan operation can provide improved IEQ, there are energy consequences, both in terms of increased fan energy consumption (though small) and increased RC space conditioning load.

Regression relationships were developed using daily average outdoor air temperature and indoor air temperature as the dependent variables. These regression relationships were then used for both comparing the monitored energy use, eliminating any weather effects, and with full-year weather data to allow for comparison between DOE2 projections and the monitoring-based regression relationships.

Prior to completing comparative runs for the 16 California climate zones, the DOE2 model needed to be validated with the monitoring data. Reconciling daily variations in thermostat control with actual DOE2 inputs was a time consuming effort. To most closely mimic reality, the validation runs were completed with assumptions consistent with the field data. The primary impact was that for the advanced hybrid cases, the heating thermostat was maintained continuously (no setback) and minimum outdoor air was always being delivered during the heating season.

3.4 DOE2 Modeling

Prior DOE2 modeling utilized assumed thermostat and lighting schedules based on a combination of standard school models and a small sample of previously monitored RCs (DEG, 2000). These assumptions were updated based on the monitoring data collected at the Cupertino and Modesto sites. More accurate schedules should improve the accuracy of the savings projections. In the prior analysis (DEG, 2001), four different RC envelope / HVAC system configurations were modeled using DOE-2.1E release 130. The base case consisted of the standard envelope with the standard HPAC system and fan operation set to cycle on with compressor operation. The three comparison configurations were:

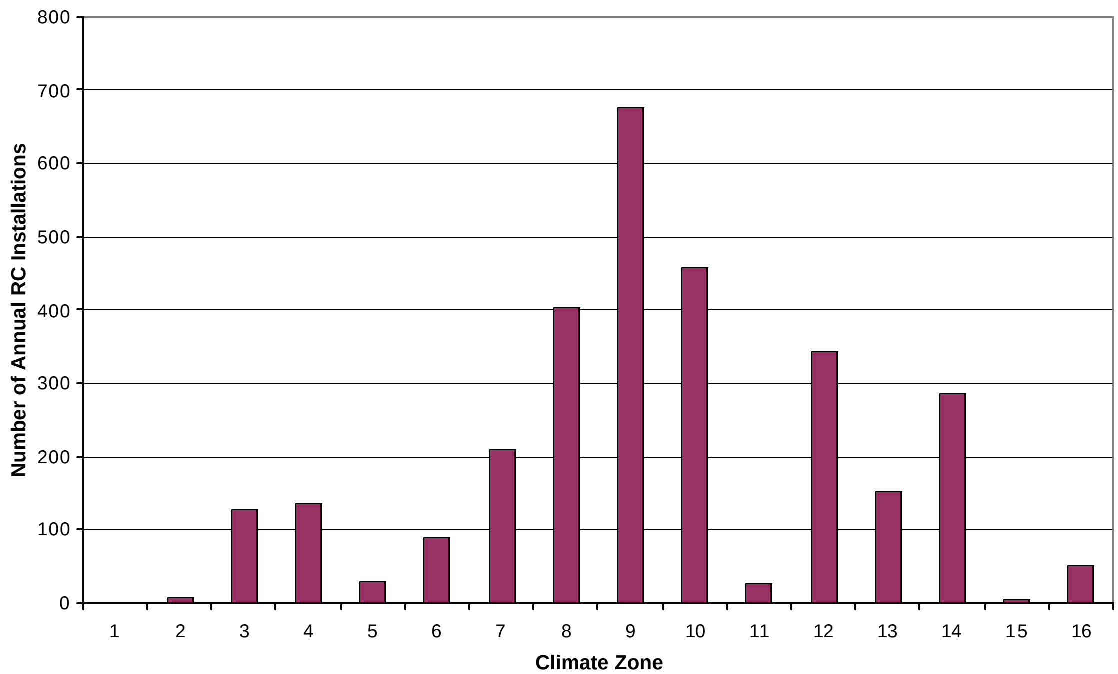
1) Standard envelope and HPAC system but constant fan operation to provide outside air flow to meet state code during occupied hours, which shows the energy impact of constant outside air.
2) Improved envelope with the standard HPAC system and a cycling fan (to demonstrate the impact of envelope measures alone).
3) Improved envelope with the advanced hybrid system (to demonstrate performance of the proposed package).

For this study, the base case was assumed to meet the upcoming 2005 Title 24 standards including an improved envelope, 12 SEER HPAC, and continuous fan operation. Simulations were completed using lighting and thermostat schedules determined from the field monitoring. These simulations were completed assuming traditional school year schedules, not year-round schedules. This assumption should generate conservative savings estimates as annual cooling loads are lower for the traditional school schedule.

3.5 Statewide Projections

An important objective of this project is to extrapolate performance and savings to a statewide basis. Annual estimates of California RC construction are approximately 4,000 units per year (CARB, 2003), although class size reduction programs have boosted RC construction levels to close to 10,000 in recent years. Analyzing California Department of Education data showing K-12 enrollment projections by county, we have generated estimates of RC placement on a climate zone basis. Figure 2 plots where the projected 4,000 RCs built annually will be installed. The greater Los Angeles area (climate zones 8-10) is projected to account for over half of annual RC installations.

Figure 2: Projected Annual RC Installations by Climate Zone



To determine statewide energy demand impacts, RC simulations were completed for each of the 16 climate zones for both HPAC systems (nominal 6.8 HSPF, 12 SEER) and advanced hybrid systems. Statewide projections were determined by factoring the "per unit" impacts by the expected number of installations in each climate zone. Operating cost savings were computed based on statewide average commercial electric rate of $.1487/kWh[2] and an assumed statewide average of $.74 per therm[3].

[2] www.energy.ca.gov/electricity/statewide_weightavg_sector.html

[3] Monthly weighted California commercial gas rates from EIA for December 2001 to November 2002 average $.60/therm (see www.eia.doe.gov/emeu/states/ngprices/ngprices_ca.html), however short-term expectations for natural gas prices are considerably higher. The more conservative $.74 per therm assumption is based on PG&E G-NR1 rates over the previous twelve months.

Statewide runs were completed to insure comparable loads and IEQ conditions in both cases. Table 4 summarizes DOE2 inputs for these runs. Two key areas where the statewide simulations will demonstrate improved energy savings relative to the monitoring results are the incorporation of continuous outdoor air during occupied periods and elimination of heating operation during non-occupied periods.

Table 4: DOE2 Inputs for Statewide Simulations

Parameter	DOE2 Input
Occupancy period	8 AM-4 PM weekdays, standard school year
Outdoor air during occupancy	315 cfm (21 people @ 15 cfm/person)
Minimum outdoor air fan power	50 W (advanced hybrid), 560 W (HPAC)
Heating Setpoint/Setback/Weekends	70ºF / 65ºF / 60ºF
Cooling Setpoint/Setback/Weekends	74ºF / 85ºF / 85ºF

4 Results

4.1 HVAC Controls Issues

Since the RC HVAC systems are ultimately controlled by the teachers, understanding their behavior is critical to analyzing HVAC system energy use. Of the two controls, the advanced hybrid thermostat is the simplest, with one setpoint and three modes, but its interaction with the system is the most complex and it was unfamiliar to the teachers – leading to unforeseen energy impacts. The HPAC thermostat was also simple, with no setback capabilities, but it too had significant impact on the HPAC energy use.

Control operation had the largest impact on the advanced hybrid heating use. Initially, in the first week of heating the advanced hybrid systems demonstrated inadequate heating capacity due to a combination of low hot water heater set point and construction debris reducing the water flow rate through the piping. To counteract the low capacity, teachers left the systems running in heat mode overnight to minimize the morning pickup load. This operating behavior continued even after the system problems were corrected, leading to higher monitored gas usage.

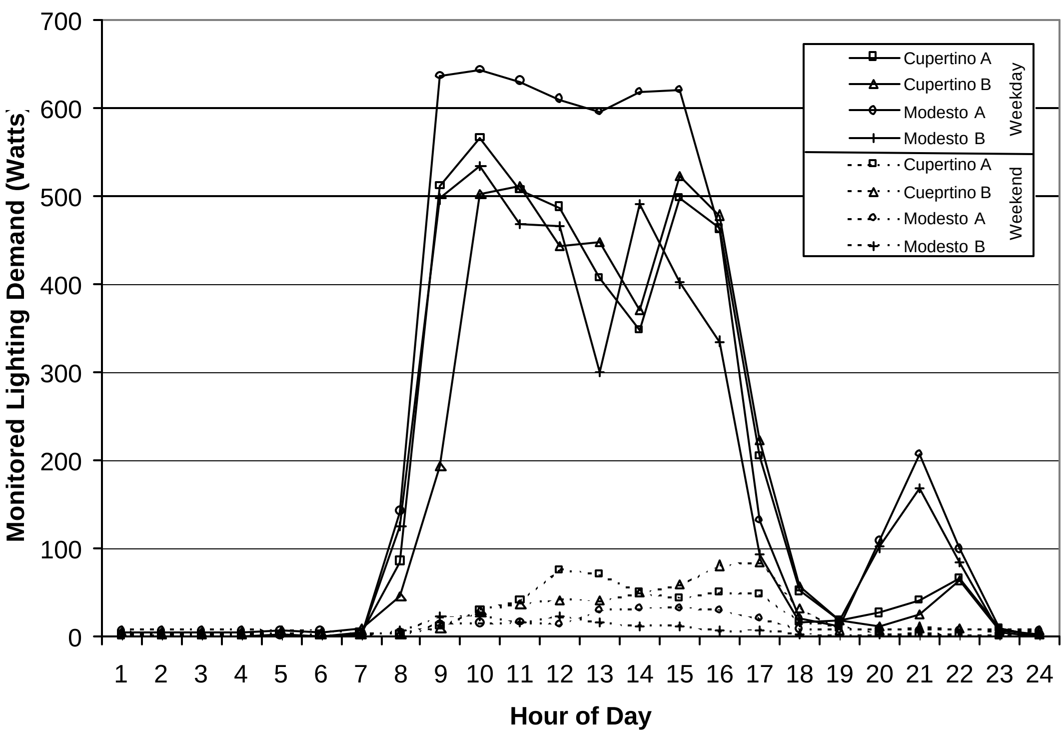
As has been observed in previous RC monitoring projects, the HPAC thermostat was operated almost exclusively in the "auto" fan mode. In this mode, the fan (and minimum outdoor air) only comes on during compressor operation. In heating mode, data suggested the teachers were using the thermostat as a "switch," turning it to heat mode with a high set point when indoor conditions became cool. The consequence of this behavior was an average of 80% of the heating energy use was due to the electric strip heat. Data also showed numerous instances of the HPAC system running for 1-2 hours after occupancy had ended and then shutting off, suggesting that the lock-out timers were highly effective.

4.2 Monitored Lighting and Thermostat Schedules

Prior DOE2 modeling assumed "typical" usage schedules and fixed thermostat setpoints during occupancy. Assumed heating thermostat setpoints were 70ºF during weekday occupancy period (8 AM to 4 PM) with 65ºF night setback, and 60ºF fixed setpoint on weekends and holidays. Assumed cooling setpoints were 76ºF during normal occupancy, and 85ºF for other hours.

Monitoring data from the four RCs reflected the impact of real world operation and the impact the teachers/HVAC Operator had on overall energy use. Lighting controls for the three lamp T8 fixtures include switching to operate one lamp, two lamps, or three lamps. Figure 3 plots average weekday and weekend (including holidays) lighting demand for the four RCs for the entire monitoring period[4]. Three of the four average weekday plots show very similar operation with a morning rise, lower use during the day including a drop at lunch, and then a second rise at the end of the school day. The fourth site, Modesto RC A, demonstrated a much flatter profile at an average demand 35% higher than the other three sites, which indicated the impact of teacher behavior on actual lighting levels. The small peaks at 21:00 and 22:00 are due to classroom cleaning by the janitorial staff. The small weekend peaks at midday in Cupertino RC A and in the afternoon in Cupertino RC B were likely due to teachers working to prepare for the upcoming week's lessons.

Figure 3: Monitored Lighting Profiles for All Classrooms



[4] Monthly and seasonal variations in the lighting profile were not significant (<10%) after accounting for holidays and vacations days, due to the monitored RCs lack of significant daylighting.

Figure 4 plots overall averages of the monitored weekday/weekend lighting schedules. This averaged profile will be used in DOE2 for annual energy use projections. The original "estimated" profiles are also plotted for comparison. Except for the dip at noon and the evening use, the profiles are very similar and the impact of using the new profile will be small.

Figure 4: Average Monitored Lighting Profiles

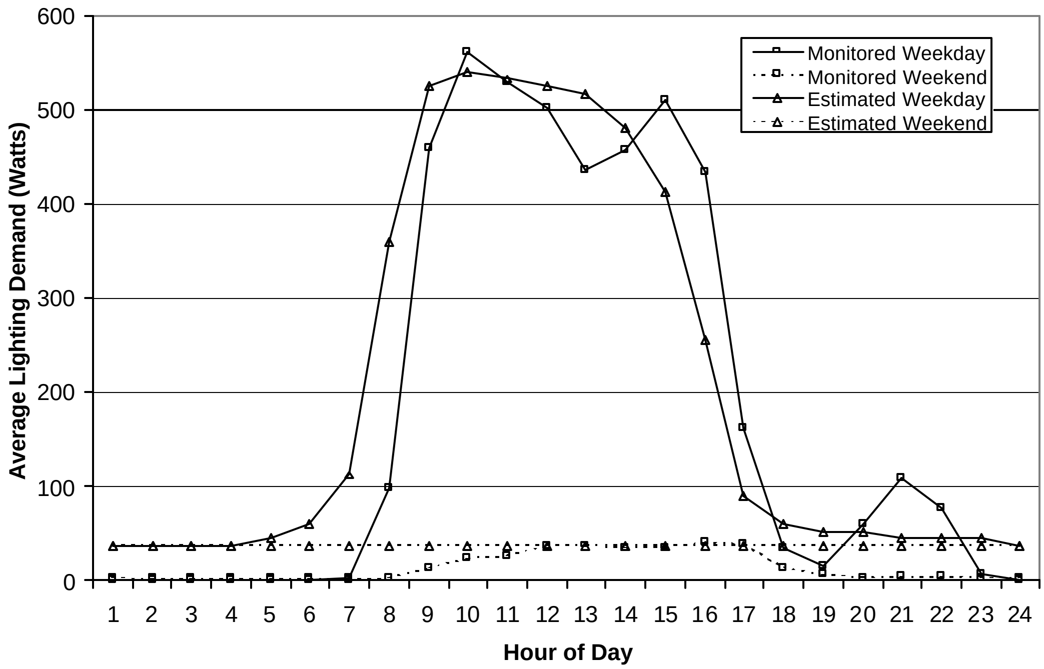


Figure 5 plots monitored thermostat setpoints for both the HPAC and the advanced hybrid HVAC systems. Since thermostat setpoint is not directly monitored, it was calculated by determining the indoor air temperature when the operating cycle ended (i.e., thermostat was satisfied). Data were plotted for heating and cooling operation modes. Missing data indicated hours for which no "end of cycle" points were recorded and the system was presumed to not be operating. The advanced hybrid heating data indicate continuous operation throughout the day. HPAC cooling data indicate that at the end of the day the unit was not immediately turned off (dips below 66ºF at hour 18) due to the operation of the four-hour lock-out timer.

Figure 5: Monitored Temperature at Termination of HVAC Operating Cycle

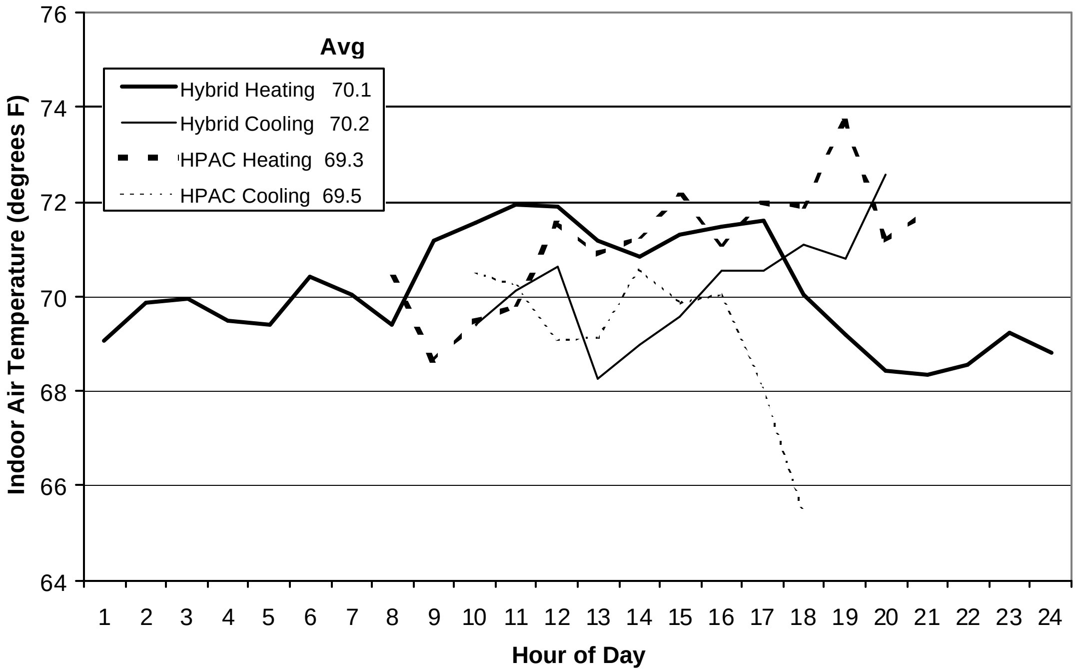
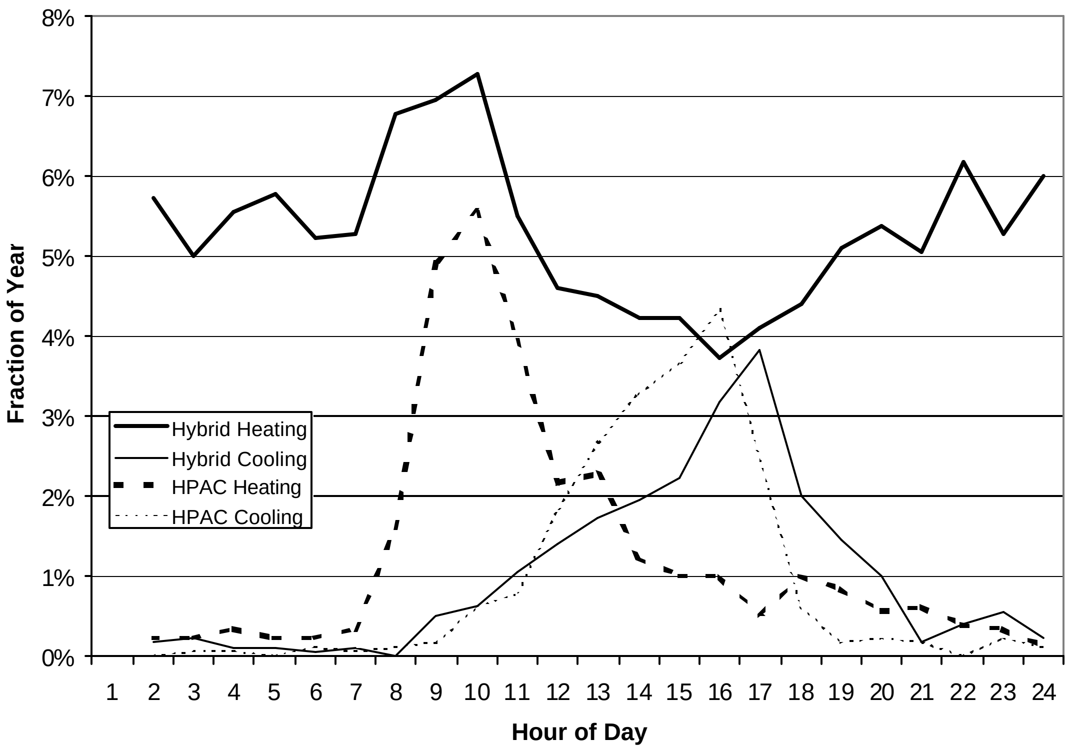


Figure 6 renders this data in a slightly different format to demonstrate when HVAC operating cycles were most commonly terminated. Conventional HPAC operation shows a pattern consistent with expected space condition loads. A majority of the heating cycles terminated in the mid- to late morning, while cooling cycle termination increased towards the end of the school day. The advanced hybrid system demonstrated a different pattern. Due to the previously mentioned temporary low heating capacity problems, some of the teachers left the system operating continuously, even after the problems had been corrected, resulting in a fairly flat cycle termination profile. The advanced hybrid system shows a cooling pattern similar to HPAC cooling, although slightly broader.

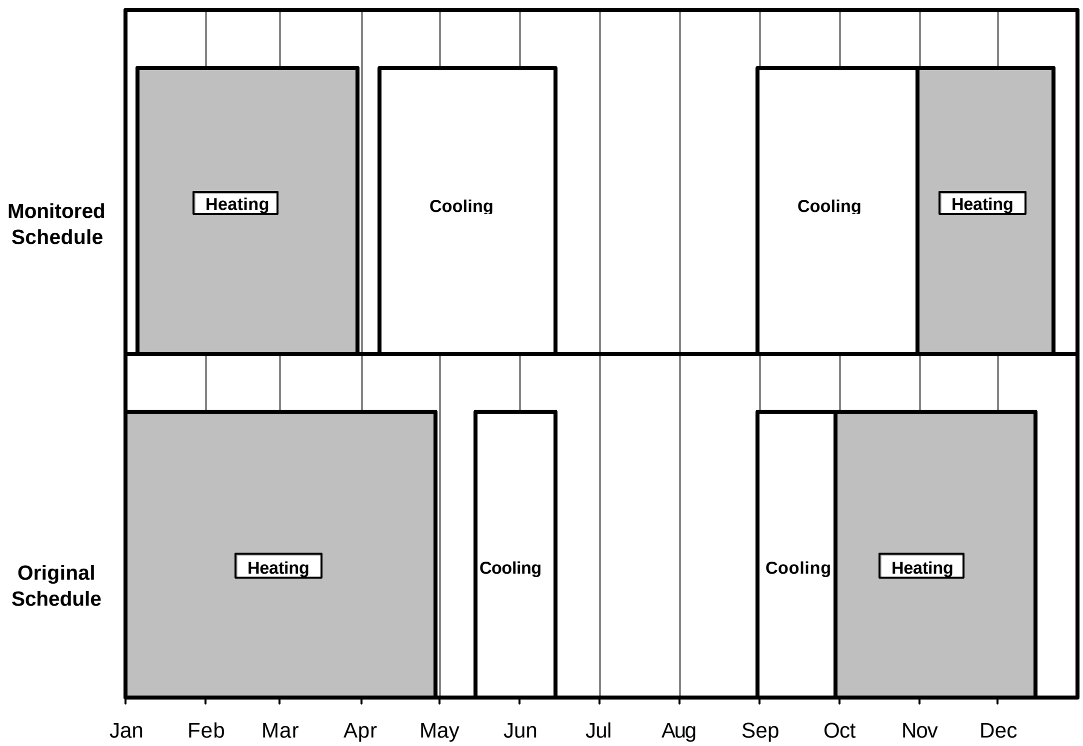
Figure 6: Frequency of HVAC Cycle Termination vs. Time of Day



On average, the HPAC system heating setpoints were found to be 1ºF higher than for the advanced hybrid system, and HPAC system cooling setpoints were found to be 1ºF lower. The monitored heating and cooling setpoints were also significantly tighter than assumed in the original DOE2 model. For the revised DOE2 modeling, tighter setpoints were modeled based on the observed thermostat operation.

Figure 7 compares the seasonal schedules used for the original DOE-2 simulations and those developed from the monitoring data. The principle difference is the longer cooling seasons observed with some minor differences in length and location of breaks. The school year starts August 30th in cooling mode, with heating mode starting after October 31st until the beginning of winter break, December 15th. The heating mode continues from January 6th to the end of spring break (March 29th in Modesto and April 13th in Cupertino) and the cooling mode was assumed for the remainder of the school year. By assuming a switch from heating to cooling mode operation, our DOE2 modeling will slightly underestimate space conditioning in the swing seasons when both heating and cooling was observed on certain days.

Figure 7: Yearly Operation Schedules (Traditional School Year)



4.3 Monitored Space Conditioning Energy Use

Figures 8-10 present monitored daily energy use in both heating and cooling modes for the two system types and two climates. Electrical energy use for the advanced hybrid is comprised of fan energy, both during heating cycles and for providing continuous outdoor air, and a small amount of pumping energy. The advanced hybrid consumes only about 50 Watts of fan energy when operating in outdoor air ventilation mode. The winter impact on gas use, however, can be significant if the system is operated to maintain temperature 24 hours a day.

Figure 8 plots daily heating energy use for the base case HPAC system and the advanced hybrid system. Monitored HPAC system energy use was higher for Modesto than for Cupertino, due both to colder winter weather and also fewer students (lower internal gains). Advanced hybrid system electrical energy use was considerably lower than for the HPAC units, since only fan and pumping energy was included. Cupertino advanced hybrid system energy use was slightly higher than in Modesto, probably due to higher internal and ventilation air loads.

Figure 8: Monitored Daily RC Heating Electrical Energy Consumption

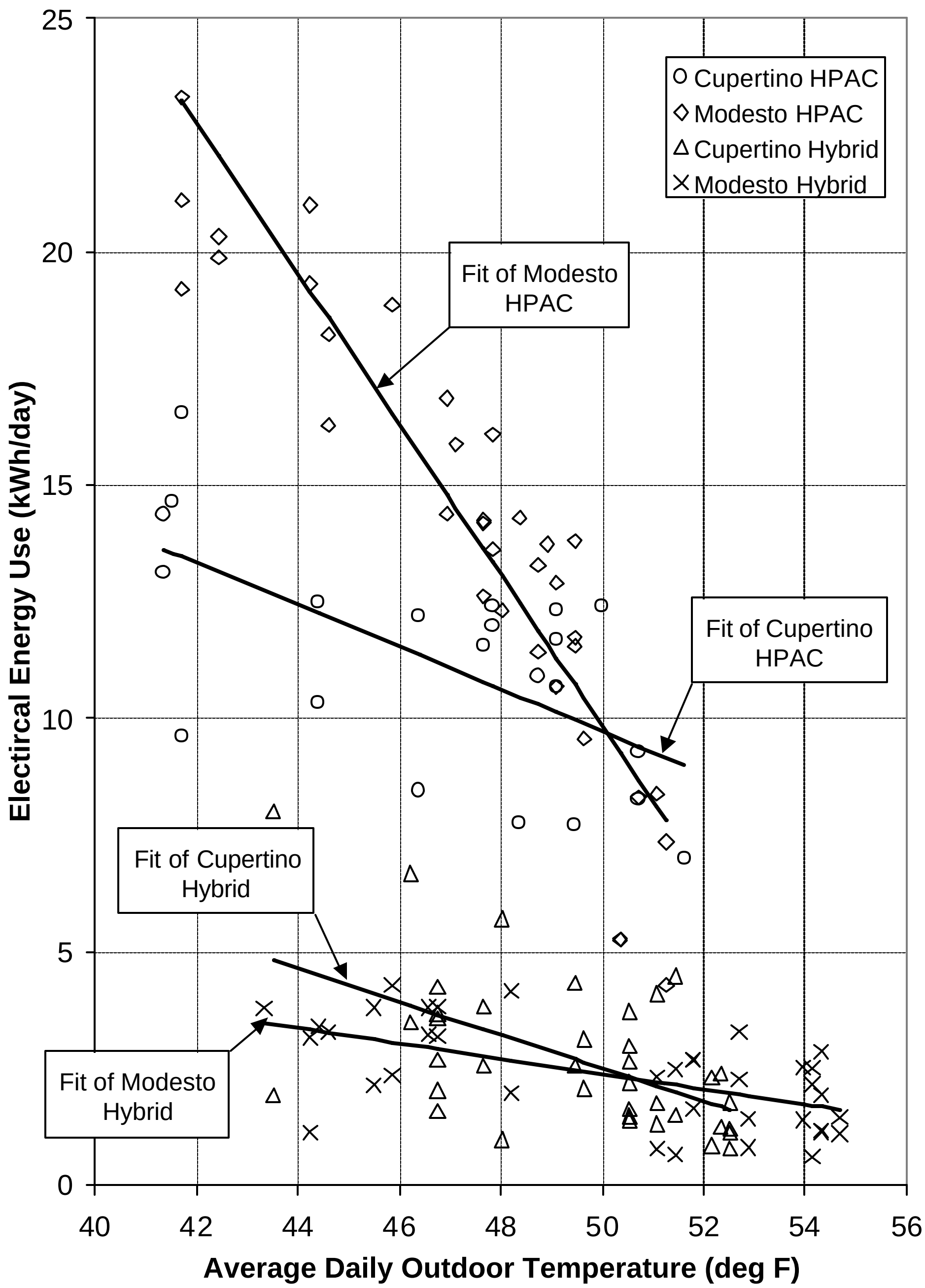


Figure 9 plots daily heating gas energy use for the advanced hybrid instantaneous gas water heater. Surprisingly, the Cupertino gas use was higher than in Modesto, which was most likely due to continuous heating operation at a higher ventilation airflow rate. In completing statewide projections, DOE2 simulations will compare performance with both base case and high performance systems providing minimum outdoor air during occupied hours only.

Figure 9: Monitored Daily RC Heating Gas Energy Consumption

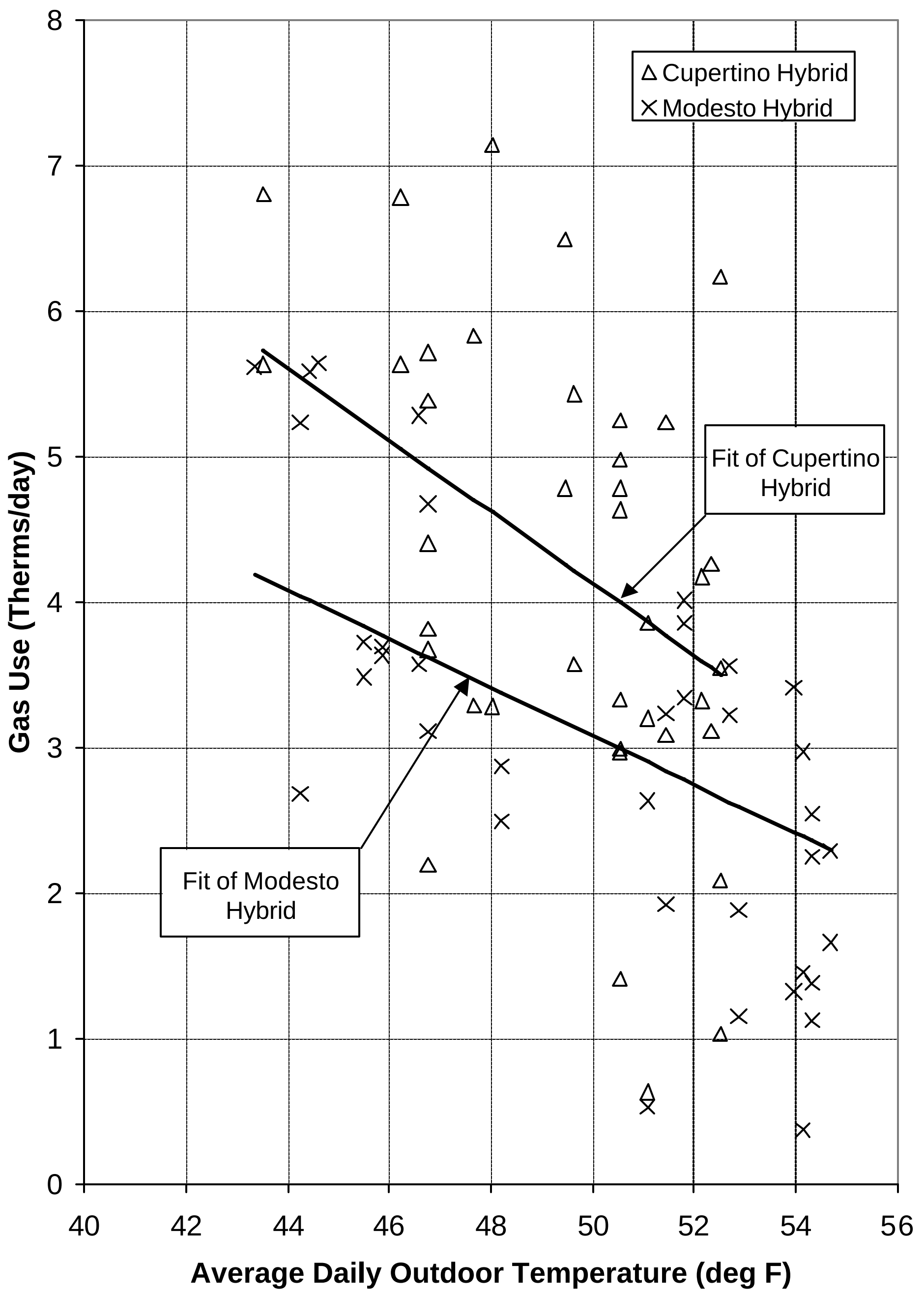
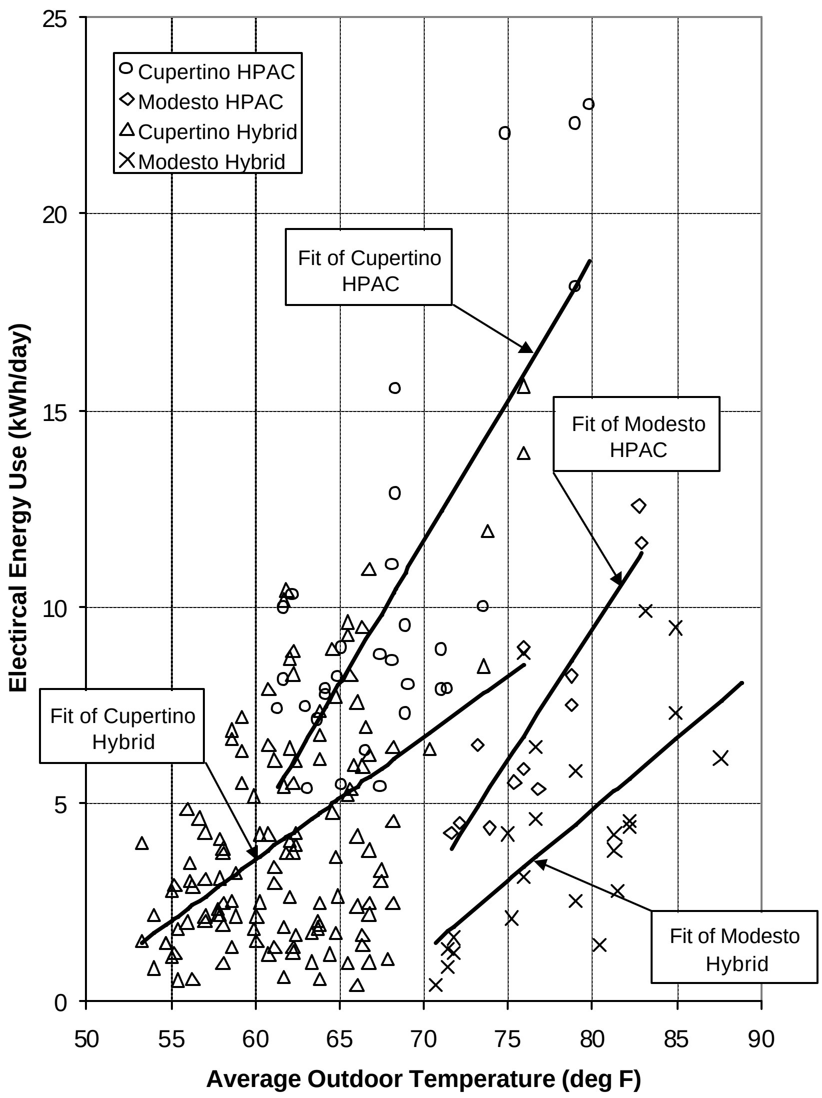


Figure 10 plots cooling electrical energy use for the two system types in both locations. The Cupertino RCs displayed cooling energy use at lower average temperatures than the

Modesto RCs. Although the magnitude of the difference is greater than anticipated, there were two factors likely contributing to this deviation. First, the higher internal gains in the Cupertino RCs due to 50% higher enrollments, and the influence of teacher preferences, resulted in the need for cooling at lower temperatures. Second, the higher outdoor air ventilation rates at Cupertino would contribute to afternoon cooling loads earlier than in Modesto. Given the fewer data points for Modesto, we have greater confidence in the validity of the Cupertino regression relationships. Advanced hybrid data demonstrated savings in both locations, consistent with our expectation of how the IDEC unit should perform[5].

Figure 10: Monitored Daily RC Cooling Electrical Energy Consumption



[5] As dry bulb temperatures increase, wet bulb depression also increases, which should contribute to improved performance (greater savings) relative to vapor compression systems at higher ambient temperatures.

Table 5 summarizes the linear fits to the regression lines shown in Figures 8-10. Advanced hybrid system gas use was also found to be statistically dependent on indoor air temperature, which acts as an indicator of continuous operation. These regression equations are used to project annual energy usage at both Cupertino and Modesto for the model validation comparisons.

Table 5: Summary of Energy Use Regressions

	Constant	*Toutdoor Coefficient*	*Tindoor Coefficient*	*R^2*	*Number of points*
Cupertino					
HPAC					
Heating	32.3	-0.451		39%	21
Cooling	-38.9	0.722		58%	29
Advanced Hybrid					
Heating	20.2	-0.353		30%	38
Cooling	-15.1	0.311		23%	125
Gas Use	3.4	-0.271	0.215	66%	154
Modesto					
HPAC					
Heating	90.7	-1.617		84%	35
Cooling	-43.6	0.663		80%	11
Advanced Hybrid					
Heating	10.6	-0.164		35%	36
Cooling	-24.0	0.361		41%	22
Gas Use	-0.52	-0.149	0.158	90%	76

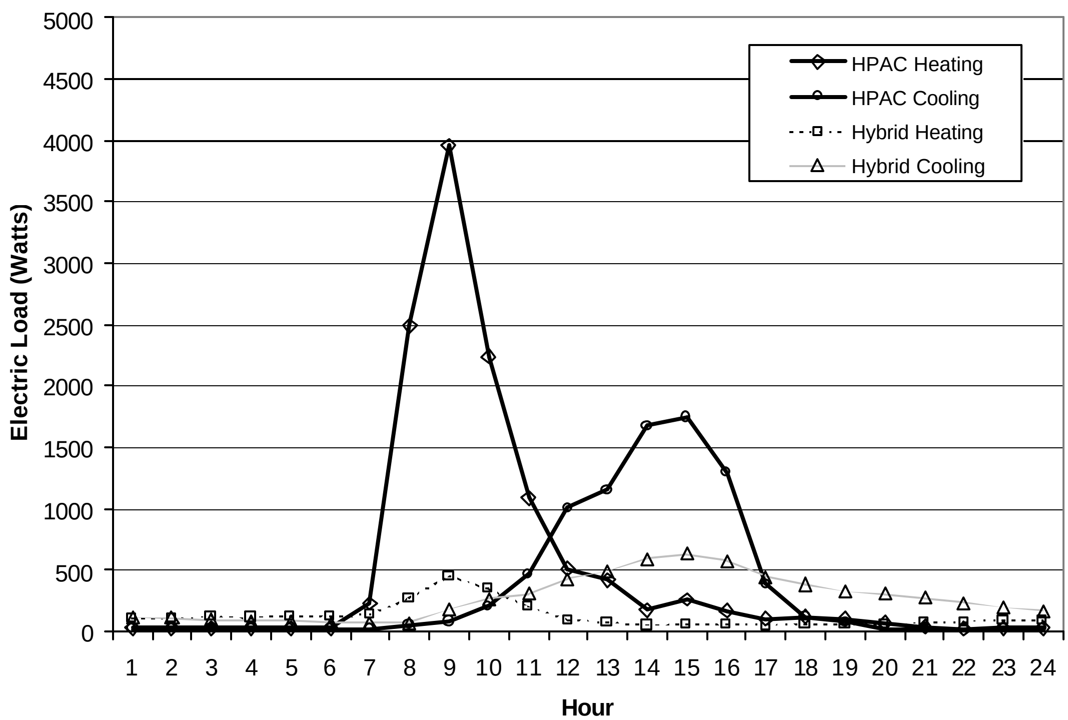
Table 6 summarizes extrapolated full-year energy use at Cupertino and Modesto based on actual weather data. The results compensate for the weekly switching of HVAC system type. As previously discussed, Modesto cooling energy use was considerably lower than at Cupertino. The advanced hybrid system demonstrated electrical savings in both locations, although projected full-year gas use was high due to heating during unoccupied periods. For the four study RCs, only 22% of monitored gas use occurred during occupied hours.

Table 6: Projected Annual Energy Use (Actual Site Weather)

Energy Use	*Electric (kWh)*		*Gas (therms)*
	HPAC	*IDEC*	*IDEC*
Cupertino			
Heating	352	94	223
Cooling	569	389	
Total	922	483	223
Modesto			
Heating	516	115	168
Cooling	206	91	
Total	722	206	168

Figure 11 plots averaged hourly electrical demand for the HPAC and advanced hybrid systems in both heating and cooling operating modes. (Appendix A figures A2-A5 contain profiles from each of the four sites, which were averaged to generated Figure 11.) The plotted data averages the hourly demand over the most extreme days (based on average outdoor air temperature) for each season. The plot is intended to demonstrate the characteristic average demand profile of the two system types. The extreme days[6] were selected to avoid the complications associated with days in which both heating and cooling operation occurred. On average, the advanced hybrid system reduced peak heating electricity demand by 89% and peak cooling demand by 64%.

Figure 11: Average HPAC and Advanced Hybrid Hourly Demand Profiles



4.4 Comparison of DOE2 and Monitored Space Conditioning Energy Use

DOE2 model validation is needed to ensure the statewide simulation runs generate results consistent with the monitoring data. To complete this exercise, the regression relationships in Table 5 were combined with DOE2 TMY weather files (Sunnyvale was used for Cupertino and Fresno for Modesto) to predict full-year consumption. Monthly usage was compared to DOE2 simulations of HPAC and advanced hybrid systems operation using the same weather locations. DOE2 simulations were completed assuming heating and cooling operation during non-occupied periods (consistent with the overall monitoring data). In addition, HPAC system heating and cooling electric input ratios (EIR's) were adjusted from the original manufacturer's assumptions to values

[6] Between nine and 21 days were averaged to compile this plot.

obtained from the full-season monitoring data. To achieve this, the 47ºF heating coefficient of performance (COP) was de-rated from 3.2 to 1.9. This large degradation is primarily due to much higher monitored strip heat energy usage and unaccounted for jacket loses. Similarly, cooling EER (at 95ºF) was de-rated from the nominal 9.25 EER to a 7 EER. Figures 12-15 compare monthly heating and cooling energy use for Cupertino and Modesto based on these assumptions. (See Appendix A for more data on monitored HPAC system performance.)

Figure 12: Cupertino Heating Energy Comparison

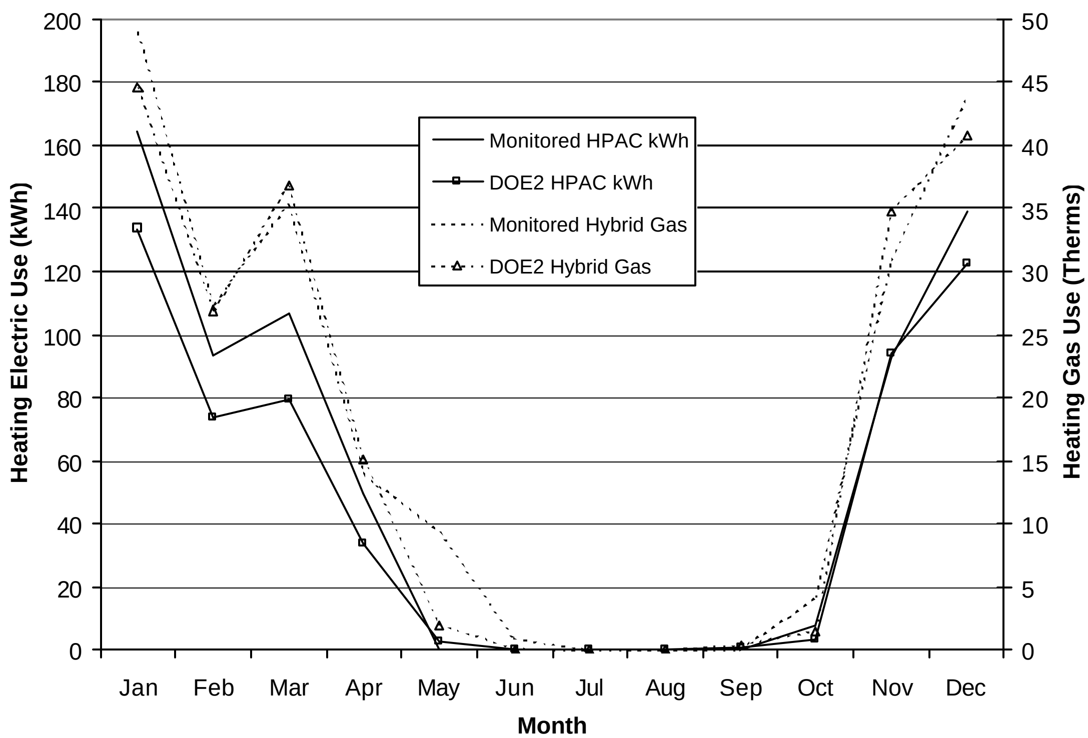


Figure 13: Cupertino Cooling Energy Comparison

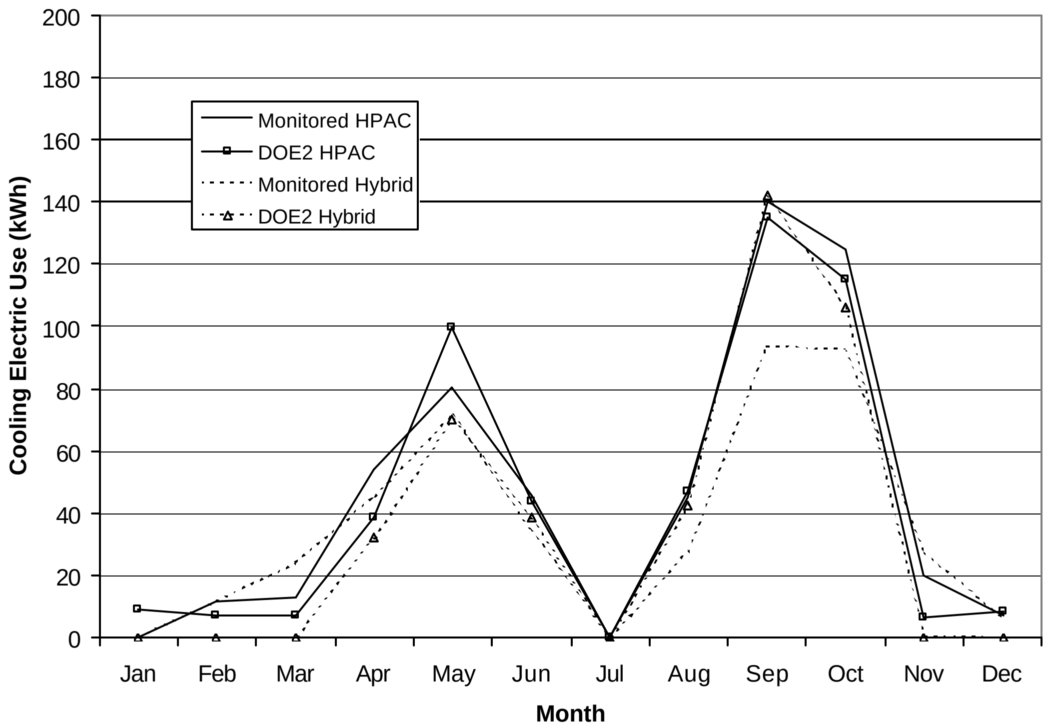


Figure 14: Modesto Heating Energy Comparison

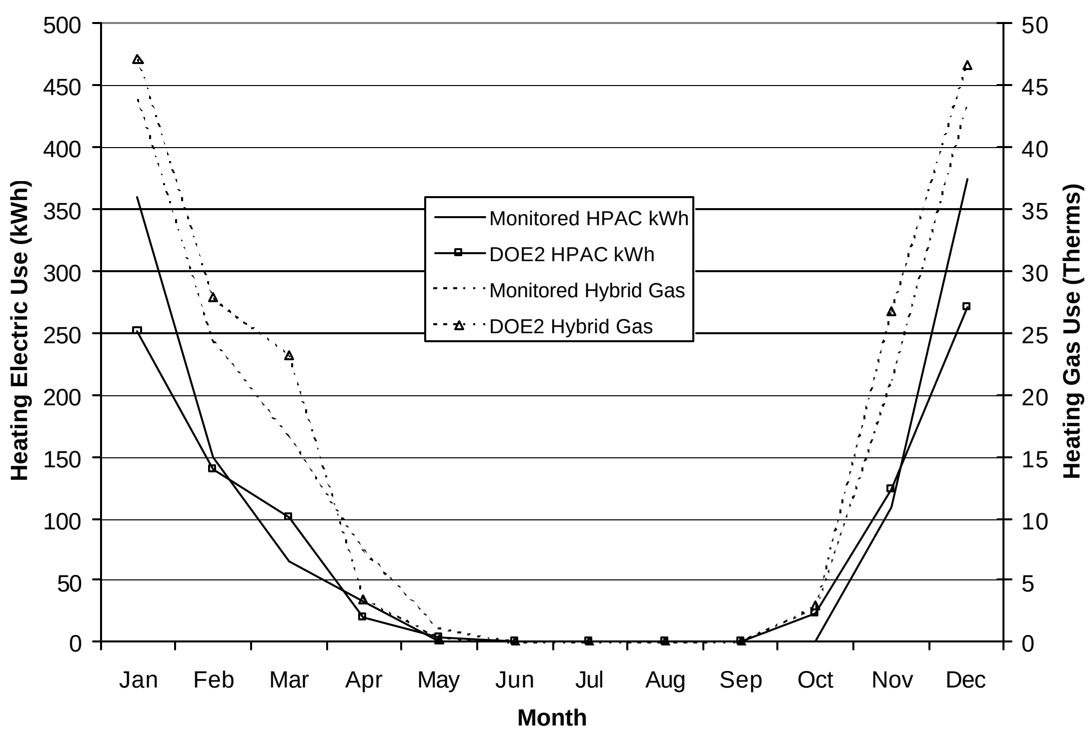
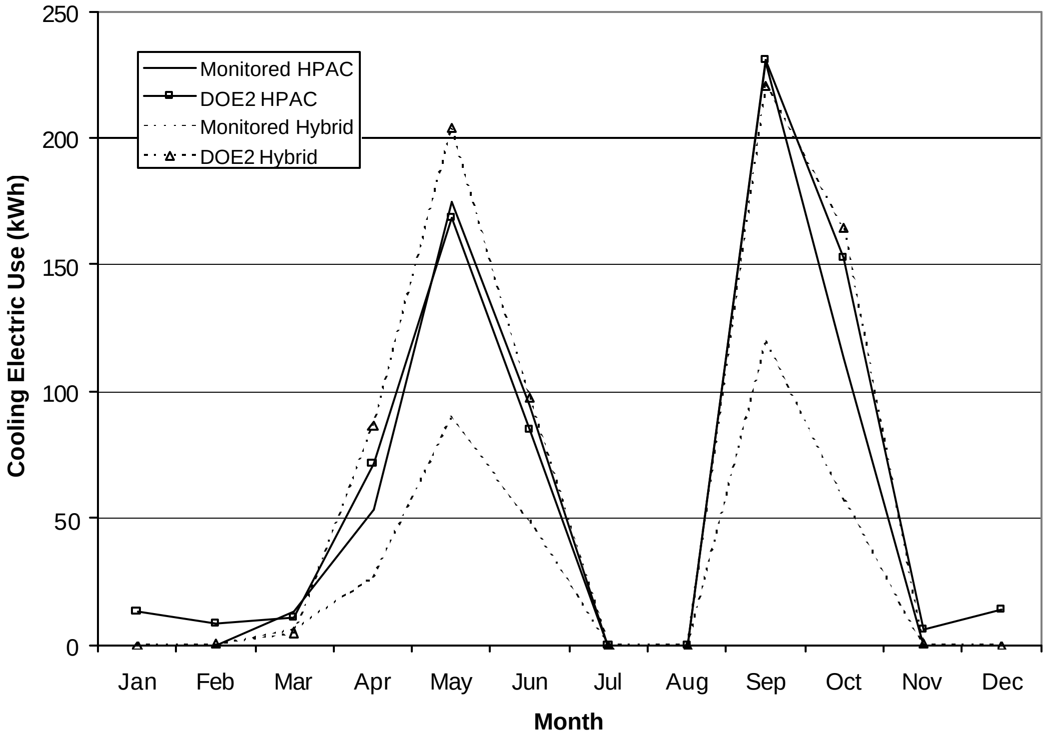


Figure 15: Modesto Cooling Energy Comparison



The comparisons of monthly "actual" and "simulated" energy use is fairly close. DOE2 tends to slightly underestimate HPAC system heating energy use (e.g., Cupertino winter) as it is difficult for the program to accurately resolve strip heat operation with an hourly time step[7]. The difference between monitored and DOE2 values in Cupertino in May (Figure 13) may be due increased use of doors and windows for natural ventilation. Advanced hybrid system cooling is complicated by the impact of varying fan efficiency (Watts/cfm) with airflow. If the teacher adjusts the advanced hybrid system control to achieve a lower temperature, the effect would be to operate the system at a higher airflow rate, and less efficiently, than would normally be the case.

The DOE2 projections for cooling are higher than the monitored cooling energy usage. This is due to the varying schedule of cooling operation, with some days showing continuous hybrid operation and some only during occupied hours. The DOE-2 simulations assume the hybrid system is on constantly for weekdays. Given the Cupertino comparison is fairly good and the data supporting the Cupertino regression relationship is more robust, we feel comfortable in claiming the DOE2 model provides a good match with the monitored results.

[7] The six minute monitoring data clearly demonstrated frequent strip heat operation even during hours when the full-hour load is not large. An hourly model does not have the resolution to accurately resolve this.

4.5 Statewide Performance Projections

Statewide projections were completed for base case HPAC and high performance HVAC systems. As discussed in section 3.5, standardized inputs were applied to both system types to ensure comparable loads, unlike the field monitoring results. Consistent with RC requirements under the proposed 2005 Title 24 Standards, minimum outdoor air ventilation was modeled during occupied hours. This assumption impacts the HPAC system significantly since the single-speed fan must operate at a fixed 560 Watt demand, while the IDEC can provide the same amount of outdoor air with only a 50 Watt demand. Appendix B contains a complete summary of the results for each of California's 16 climate zones, while the body of the report focuses only on three zones with large RC growth potential: 3 (mild San Francisco Bay area), 9 (inland Southern California), and 12 (hot inland valley, e.g., Modesto).

Table 7 summarizes projected annual energy performance for the two system types in the three climate zones. Advanced hybrid system heating and cooling energy represents pump and controls energy only; fan energy represents blower operation. Advanced hybrid system electricity savings in these three zones were significant, exceeding 80%. DOE2 projected HPAC system cooling demands were much lower than monitored data suggested. To more accurately reflect real performance, HPAC system cooling demands were calculated using a regression relationship based on the monitored performance of the HPAC heat pump versus outdoor air temperature (see Figure A-7 in Appendix A) and the ASHRAE 0.5% summer design temperatures for the representative cities. Projected cooling demand savings exceeded 70% in these three climate zones.

Table 7: Annual HVAC Energy Use and Demand Projections

System		Annual kWh				Peak kW		Gas Use
Type	CZ	Heating	Cooling	Fan	Total	Heating	Cooling	therms/yr
HPAC	3	519	187	868	1574	4.2	4.4	0
Hybrid	3	15	5	157	177	0.2	1.3	26
HPAC	9	340	483	833	1656	5.6	4.6	0
Hybrid	9	10	17	308	335	0.2	1.3	18
HPAC	12	833	362	902	2097	7.4	4.7	0
Hybrid	12	22	13	272	307	0.2	1.3	43

Table 8 reports annual HVAC source energy (based on a heat rate of 10.239 kBtu/kWh), annual space conditioning operation costs, and projected energy and operating cost savings. For the three zones, source energy savings exceeded 65% and operating cost savings exceeded 74%. Figure 16 provides a source energy comparison for the three climate zones (Oakland =3, Burbank =9, and Sacramento =12); end uses were disaggregated. Advanced hybrid system cooling energy use is shown as fan energy, in contrast to the HPAC system where compressor energy consumption is shown for cooling.

Table 8: Annual HVAC Source Energy, Cost, and Savings Projections

System Type	CZ	Source Energy MBtu	Annual Cost	Savings MBtu	Savings Cost	Savings (%) Mbtu	Savings (%) Cost
HPAC	3	16.1	$234				
Hybrid	3	4.4	$46	11.7	$188	73%	81%
HPAC	9	17.0	$246				
Hybrid	9	5.3	$63	11.7	$183	69%	74%
HPAC	12	21.5	$312				
Hybrid	12	7.5	$77	14.0	$234	65%	75%

Figure 16: Source Energy Savings for Advanced Hybrid vs. HPAC

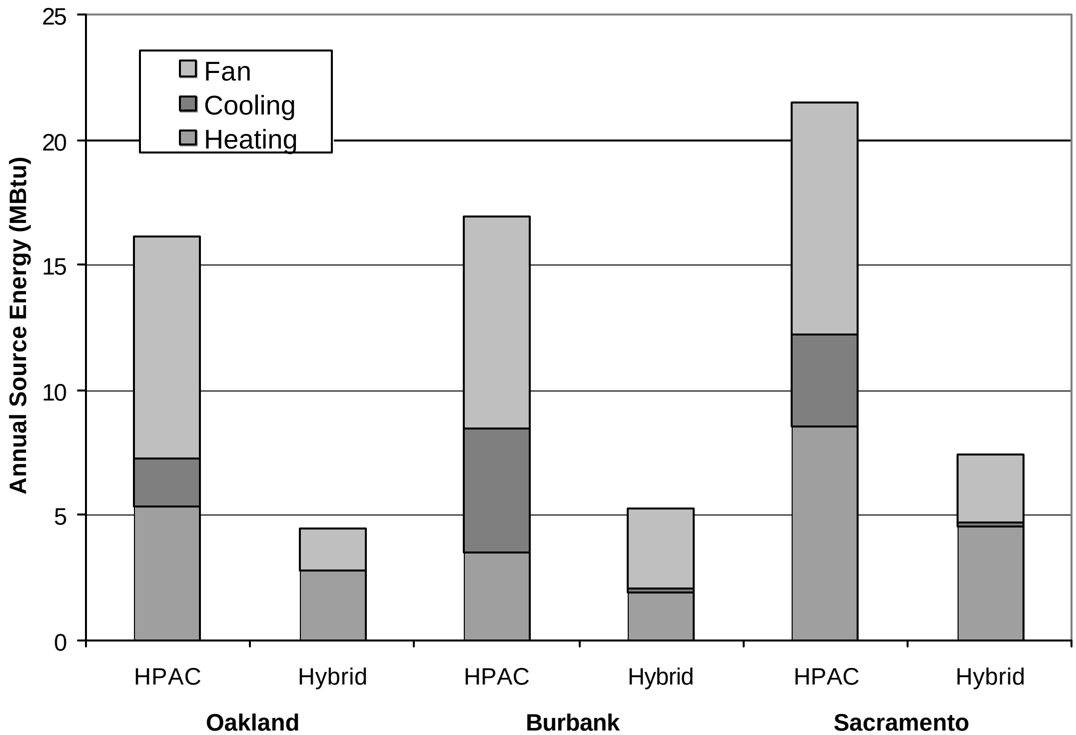


Table 9 tabulates the technical potential of replacing HPAC systems with advanced hybrid systems based on our projected placement of 4,000 RCs annually. Climate zone impacts were totaled based on the projected climate zone distribution of new RCs shown in Figure 2. Projected impacts on a statewide basis were source energy and operating cost savings exceeding 80% and demand reductions exceeding 70%. Weighted statewide average "per unit" annual impacts amounted to:

- 1,494 kWh electricity saved (82% reduction)
- 5.9 kW winter peak electric load reduction (96% reduction)
- 3.3 kW summer peak electric load reduction (72% reduction)
- 26 therm gas increase
- 13 Mbtu source energy savings (69% reduction)
- $220 annual operating cost savings, ranging from $159 to $385 (82% reduction)

Table 9: Annual HVAC Source Energy, Cost, and Savings Projections

System Type	Electric use (MWh)	Gas Use (MBtu)	Peak Demand Heating (MW)	Peak Demand Cooling (MW)	Source (MBtu)	Operating Cost
HPAC	7,253	0	24.7	18.3	74,261	$1,078,500
Hybrid	1,278	10,247	0.9	5.2	23,330	$197,600
Savings	82%	n/a	96%	72%	69%	82%

Table 10 estimates incremental costs for the advanced hybrid system relative to the 6.8 HSPF/12 SEER HPAC unit. A challenging cost variable relates to connecting gas to the RCs. The instantaneous gas-fired water heaters require larger than typical gas line sizing due to their high capacity output, even though less than 25% of their full capacity is required by the heating coil. Our estimates assumed a minimum of 10 RCs are placed at one school in close proximity to one another. We estimated a range in gas line costs with the high estimate based on the actual $10,000 extension cost, while the low estimate assumed that the water heater could be de-rated and thus the gas line size significantly reduced. Final incremental cost estimates ranged from $1,786 to $2,586 per unit. Expectations are that the advanced hybrid system incremental costs would come down if production volumes increase.

Table 10: Advanced Hybrid System Estimated Incremental Costs

Item	Estimated Cost
IDEC	$1,200
Instantaneous water heater	$800
Coil, pump, expansion tank	$220
Incremental labor	$200
Subtotal	$2,420
12 SEER HPAC	($1,200)
Net Cost	$1,220
RC manufacturer markup	$366 (30%)
Gas line extension cost	$200-$1000
Total Incremental Cost	**$1,786 - $2,586**

On a weighted statewide basis, the advanced hybrid system is projected to have a simple payback ranging from 8.1 to 11.7 years, depending upon the actual cost for the gas line extension. Projected simple paybacks are also calculated by climate zone. Table 11 summarizes paybacks based on the range of incremental costs shown in Table 10 for those climate zones where 200 or more RCs are placed annually[8]. Although paybacks as low as 4.6 years are projected for the mountainous climate zone 16, the more populous zones have longer paybacks due to lower loads (and savings). Based on average

[8] These seven zones amount to 84% of the estimated annual RC production volume.

advanced hybrid system incremental cost, an average 10.6 year payback is projected for the more populous zones listed in Table 11.

Table 11: Advanced Hybrid Projected Simple Payback

Climate Zone	Estimated RC Units /year	Simple Payback Range (years)
14	381	6.9 to 9.9
13	203	7.4 to 10.7
12	457	7.6 to 11.0
10	609	9.5 to 13.7
9	902	9.8 to 14.1
8	537	10.0 to 14.5
7	279	11.1 to 16.1

The projected performance and economic results do not account for several factors:

- Although both the HPAC and advanced hybrid systems require regular maintenance, it is critical for correct advanced hybrid system operation, especially in areas with high water mineral content. An unmaintained HPAC unit will probably still be able to provide adequate space conditioning, though at reduced efficiency. Lack of proper maintenance on a hybrid system will ultimately lead to system failure. Both school district maintenance staff and teachers need to be trained on the maintenance needs and operational constraints of the advanced hybrid system.
- The statewide average electric rate used in the analyses represents a blended rate based on energy and demand charges. The advanced hybrid system, with its significant cooling season demand reduction benefit, should generate better savings than those reported here.
- DOE-2 simulation results indicated the advanced hybrid system can maintain indoor air temperatures in each of the 16 California climate zones. In reality, in some of the areas with high outdoor wet bulb temperatures, such as Palm Springs and San Diego, the IDEC may fail to keep the indoor conditions dry enough for typical classroom activities (paper begins to become limp and stick together above 70%RH).
- A recent survey of portable classrooms found that 68% of teachers were likely to turn off the HVAC system due to noise (ARB, 2003). Although this is likely to lower HVAC energy use it will likely also lead to IEQ problems. The hybrid system's low velocity fan provides airflow at a lower noise level and therefore is more likely to be left on, as was found from the monitoring.

5 Conclusions

Monitored energy savings due to use of the advanced hybrid system in the four monitored classrooms were mixed. Although monitored cooling savings were close to expected levels, daily heating energy use was significantly higher due to operational and control problems. Even though the monitored HPAC heating efficiency was low due to high strip heat use, the advanced hybrid heating use was higher due to continuous operation.

DOE2 modeling indicated, that if control issues can be overcome, the advanced hybrid system provides an efficient alternative to conventional HPAC systems. In addition to efficient space conditioning (82% kWh savings and 72% summer peak demand reduction), the advanced hybrid system offers continuous high efficiency outdoor air ventilation. Unfortunately, the advanced hybrid technology evaluated here is not currently available as a packaged system, making it more costly in the short-term. If a market develops for the advanced hybrid system technology, competing manufacturers should appear, reducing incremental costs.

Although the advanced hybrid system offers significant energy efficiency benefits, there are still some issues to address. The IDEC system requires more frequent maintenance than a standard HPAC system. Evaporative media needs to be replaced (typically on 3-5 year intervals), and teachers and service personnel need to be trained on the operational characteristics and maintenance requirements of the system. In addition, the IDEC will have difficulty providing thermal comfort in the extreme desert regions of California where mid-summer temperatures frequently exceed 110ºF and in year-round schools in inland valley regions.

The low monitored efficiency of the HPAC system demonstrated the need for efficient heating alternatives, but the difficulty and cost of installing gas heating in a relocatable classroom project may be a significant barrier. Other possible heating systems compatible with the IDEC cooling system, such as electric ceiling radiant or an integrated heat pump, should be investigated although the systems may not be so source-energy efficient as the natural gas solution.

The importance of proper HVAC controls cannot be overemphasized. This single factor was common to both the HPAC and hybrid systems and had the greatest influence on energy use. The energy effects of controls such as ramping thermostats (to prevent strip heat use), lock-out timers, and occupancy sensors should be investigated further.

The advanced hybrid system offers great potential for improving the energy efficiency of relocatable classrooms, while also improving indoor air and environmental quality. A larger scale field test of advanced hybrid systems (with possibly an alternative heating method) would provide more data on system performance, installed costs, and teacher/staff satisfaction.

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APPENDIX A

This appendix includes more detailed monitoring data on HVAC system performance. Figures A-1 through A-5 present average demand profiles for the four RCs for the more extreme days of the heating and cooling season. The selected days, ranging from nine to 21 days depending upon climate and the operation of the RC on those days, demonstrate what typical mid-winter or mid-summer profiles look like.

Figure A-6 plots HPAC system heating demand as a function of outdoor air temperature. The selected six-minute monitoring points represented full-load operation during the six-minute interval and the surrounding time intervals, to insure 100% operation during the interval. The striking characteristic in this plot is the occurrence of heat pump strip heat across outdoor temperatures. This clearly is the major factor contributing to the low HPAC heating efficiency.

Figure A-7 plots HPAC system cooling demand as a function of outdoor air temperature. Data points were selected in a manner similar to heating. The small number of cooling data points translated into short run cycles, which meant the system was rarely reaching steady state operation. This is reflected in Figure A-8, which demonstrates EERs considerably lower than manufacturer's data would indicate.

Figures A-9 and A-10 plot monitored outdoor dry bulb temperature against NOAA data for the same day from the closest locations and a day from the TMY file with the same average outdoor air temperature. Both study sites show higher morning temperatures due to solar effects, e.g., reduced albedo off of, i.e., increased absorbance by, the asphalt playground the Modesto RCs were sited on.

Figure A-1: IDEC Gas Consumption Profile

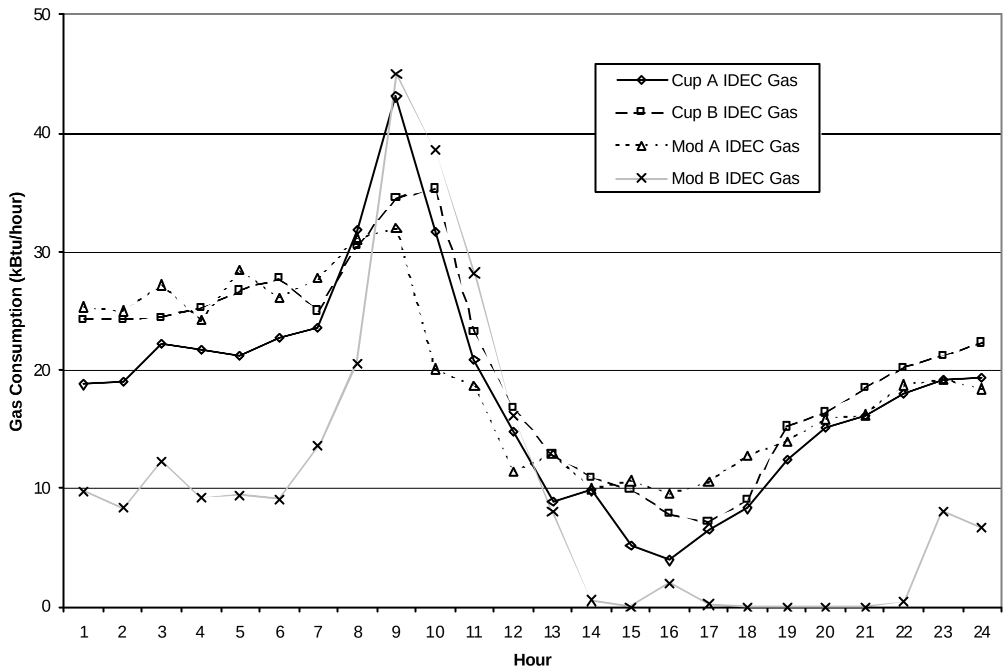


Figure A-2: HPAC Heating Electrical Load Profile

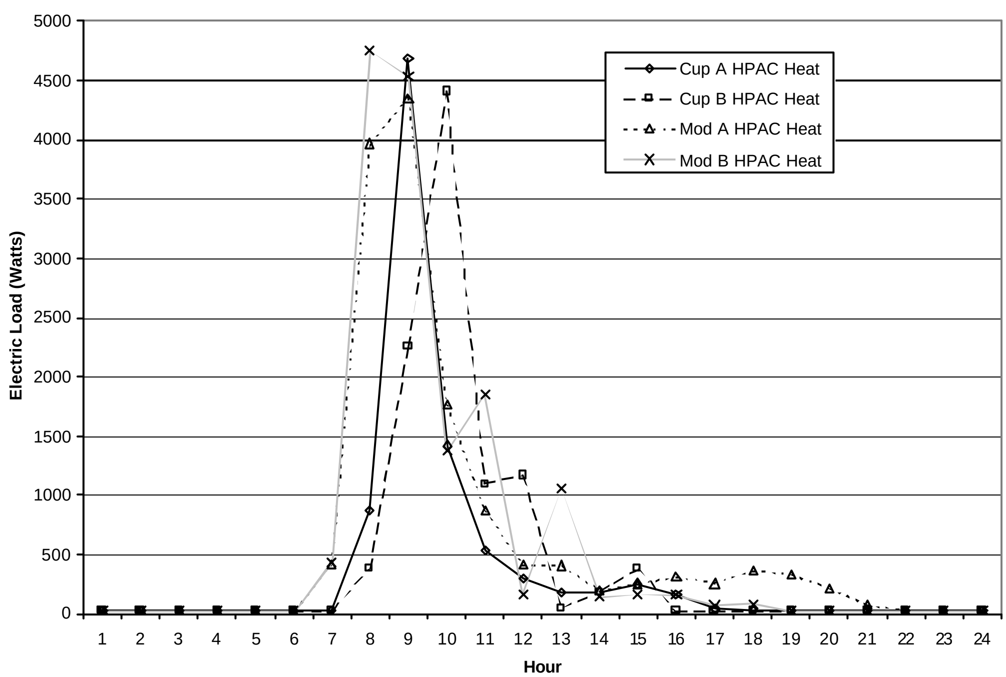


Figure A-3: HPAC Cooling Electrical Load Profile

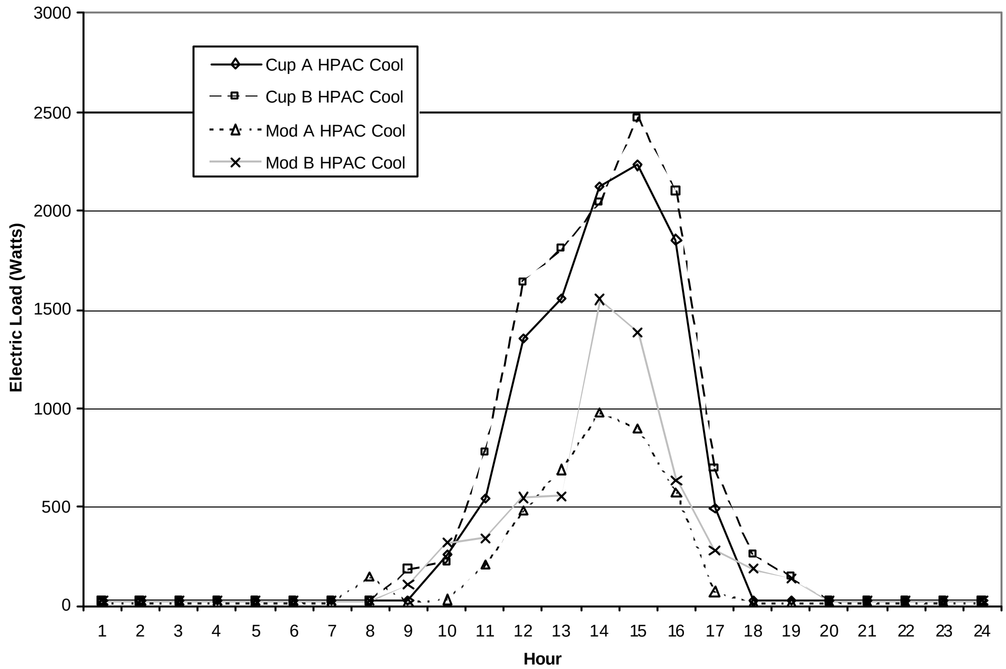


Figure A-4: IDEC Heating Electrical Load Profile

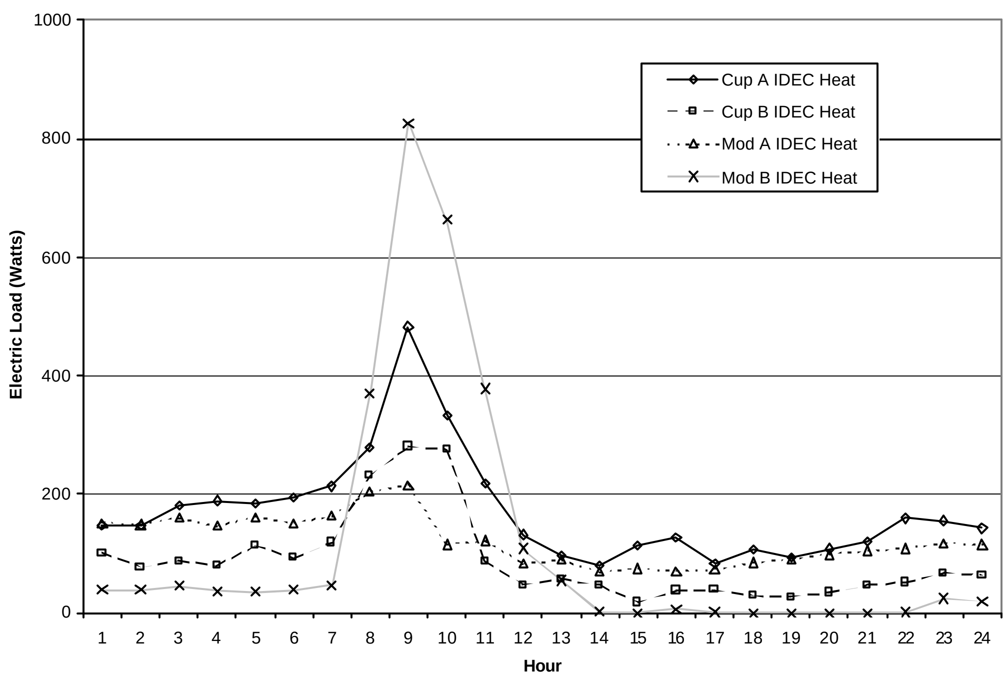


Figure A-5: IDEC Cooling Electrical Load Profile

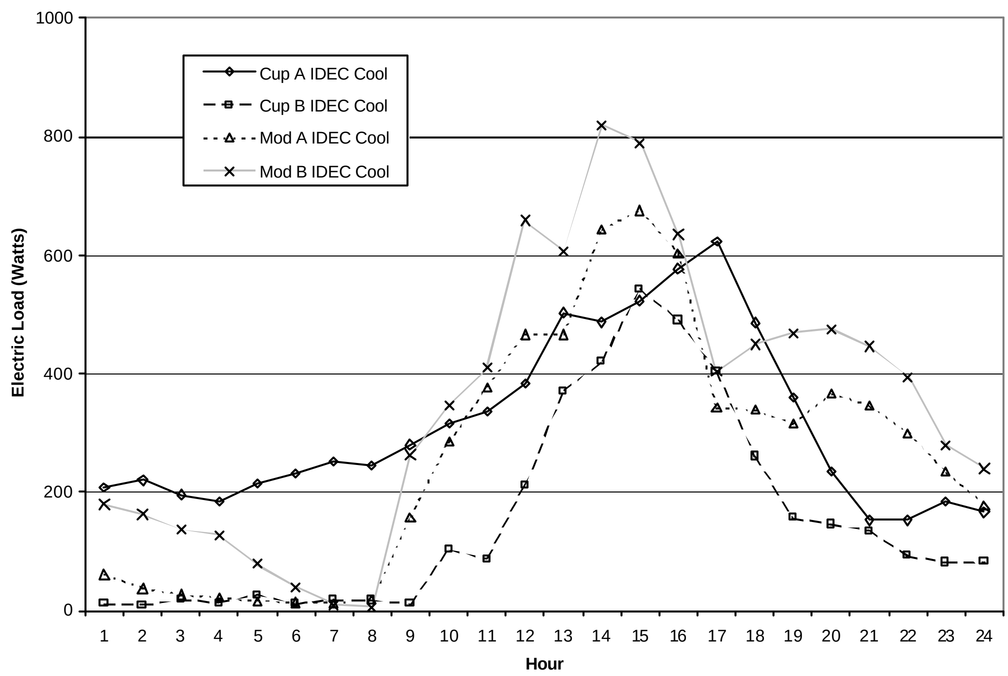


Figure A-6: HPAC Heating Demand (full-load operation)

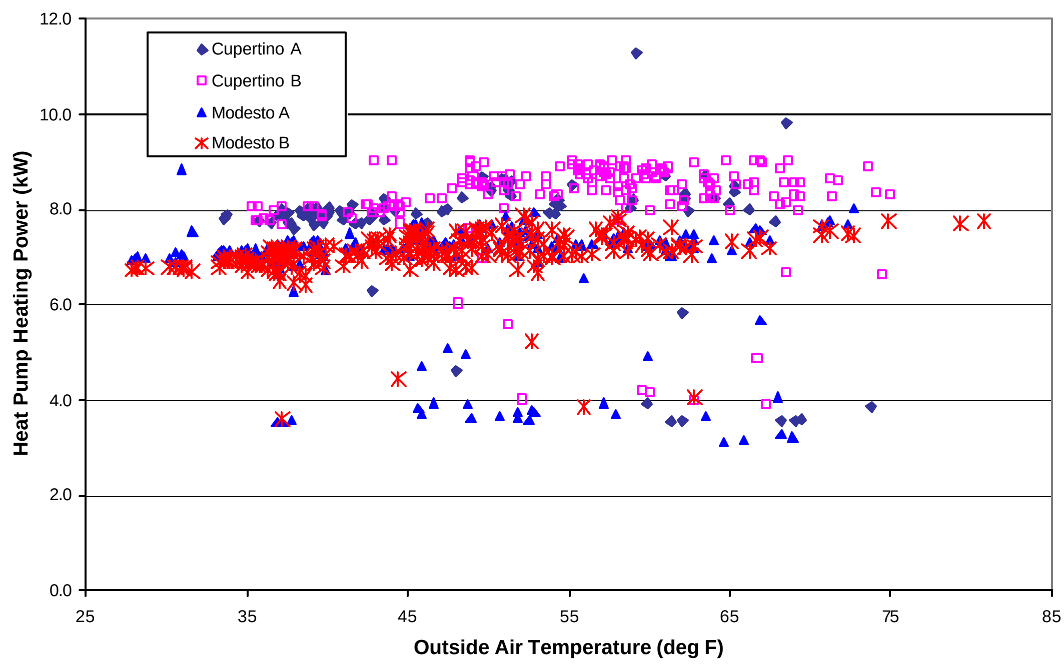


Figure A-7: Monitored HPAC Cooling Demand vs. Outdoor Temperature

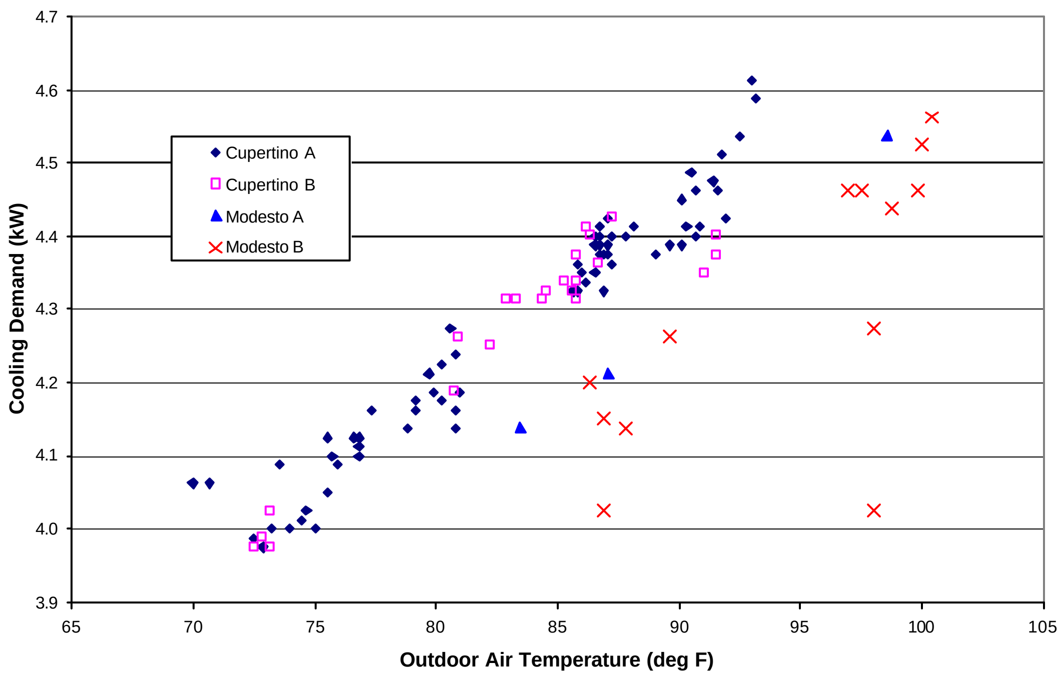


Figure A-8: Monitored HPAC Cooling EER vs. Outdoor Temperature

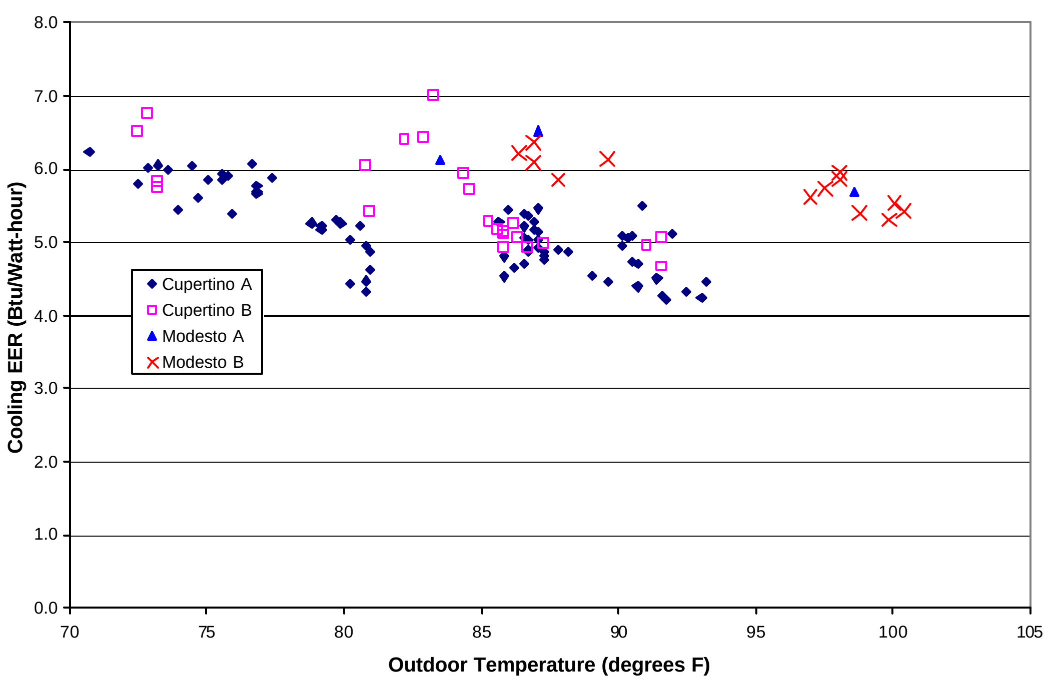


Figure A-9: Weather Data for Cupertino on June 4, 2002

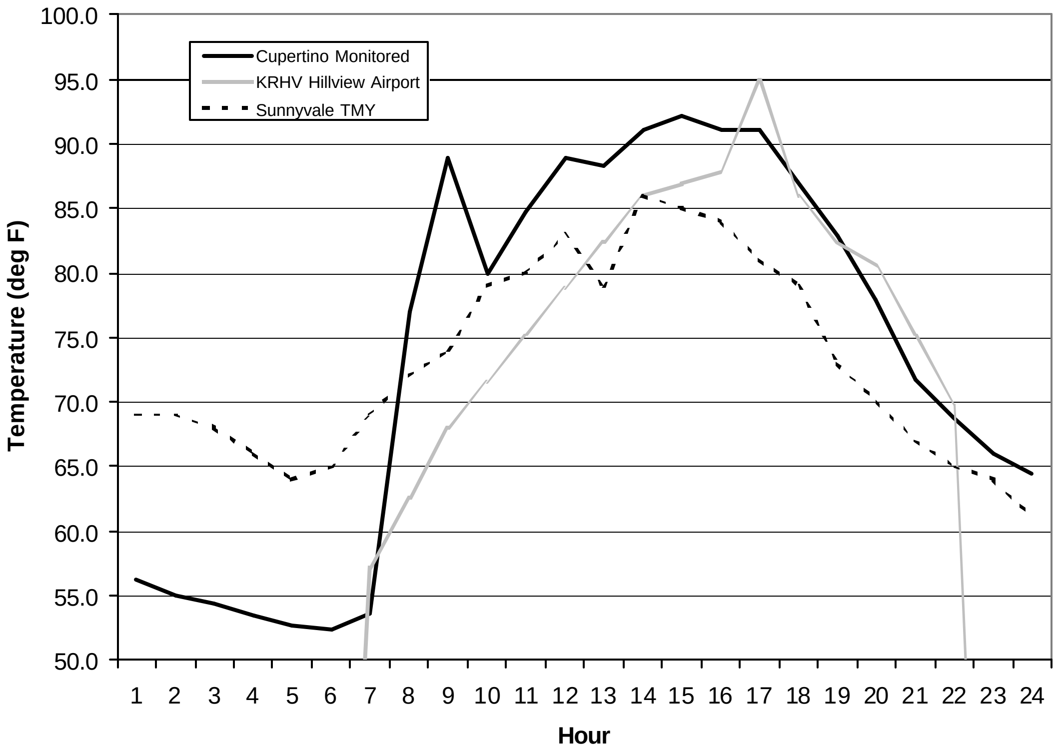
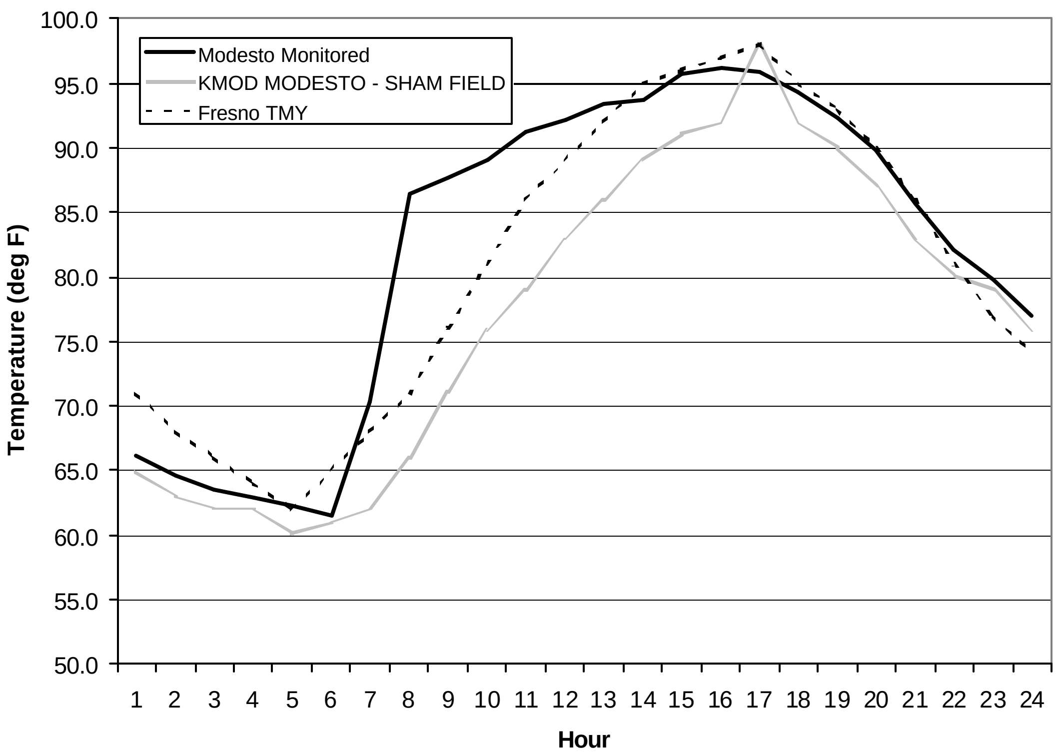


Figure A-10: Weather Data for Modesto on May 29, 2002



Appendix B: DOE-2 Simulation Results

			Electric (kWh)				Demand (kW)		Gas (therms)	Total Source	Annual		Savings		
System	CZ	Lights	Heating	Cooling	Fan	Total	Heating	Cooling	Heating	Energy (Mbtu)	Cost	Mbtu	Cost	Mbtu %	Cost %
HPAC	1	861	751	37	913	1701	6.1	3.9	0	17.42	$253				
IDEC	1	861	20	0	62	82	0.2	1.3	37	4.54	$40	12.9	$213	74%	84%
HPAC	2	861	937	285	905	2127	8.6	4.6	0	21.78	$316				
IDEC	2	861	21	10	232	263	0.2	1.3	44	7.09	$72	14.7	$245	67%	77%
HPAC	3	861	519	187	868	1574	4.2	4.4	0	16.12	$234				
IDEC	3	861	15	5	157	177	0.2	1.3	26	4.42	$46	11.7	$188	73%	81%
HPAC	4	861	639	321	881	1841	7.4	4.4	0	18.85	$274				
IDEC	4	861	16	12	222	250	0.2	1.3	32	5.76	$61	13.1	$213	69%	78%
HPAC	5	861	400	266	865	1531	5.9	4.3	0	15.68	$228				
IDEC	5	861	11	10	215	236	0.2	1.3	21	4.52	$51	11.2	$177	71%	78%
HPAC	6	861	246	316	823	1385	4.7	4.4	0	14.18	$206				
IDEC	6	861	8	9	237	254	0.2	1.3	13	3.90	$47	10.3	$159	72%	77%
HPAC	7	861	222	361	828	1411	3.3	4.3	0	14.45	$210				
IDEC	7	861	7	11	259	277	0.2	1.3	11	3.94	$49	10.5	$160	73%	76%
HPAC	8	861	270	517	841	1628	4.8	4.4	0	16.67	$242				
IDEC	8	861	8	18	335	361	0.2	1.3	14	5.09	$64	11.6	$178	69%	74%
HPAC	9	861	340	483	833	1656	5.6	4.6	0	16.96	$246				
IDEC	9	861	10	17	308	335	0.2	1.3	18	5.23	$63	11.73	$183	69%	74%
HPAC	10	861	327	514	853	1694	5.4	4.7	0	17.34	$252				
IDEC	10	861	9	16	314	339	0.2	1.3	17	5.17	$63	12.2	$189	70%	75%
HPAC	11	861	958	400	904	2262	8.9	4.8	0	23.16	$336				
IDEC	11	861	24	12	280	316	0.2	1.3	47	7.94	$82	15.2	$255	66%	76%
HPAC	12	861	833	362	902	2097	7.4	4.7	0	21.47	$312				
IDEC	12	861	22	13	272	307	0.2	1.3	43	7.44	$77	14.03	$234	65%	75%
HPAC	13	861	751	569	881	2201	7.4	4.7	0	22.54	$327				
IDEC	13	861	19	19	354	392	0.2	1.3	37	7.71	$86	14.8	$242	66%	74%
HPAC	14	861	901	514	905	2320	10.3	4.9	0	23.75	$345				
IDEC	14	861	19	14	317	350	0.2	1.3	44	7.99	$85	15.8	$260	66%	75%
HPAC	15	861	193	1207	939	2339	3.6	7.0	0	23.95	$348				
IDEC	15	861	6	32	522	560	0.2	1.3	11	6.83	$91	17.1	$256	71%	74%
HPAC	16	861	2136	117	979	3232	11.0	4.4	0	33.09	$481				
IDEC	16	861	41	4	136	181	0.2	1.3	93	11.15	$96	21.9	$385	66%	80%