Residential Indirect/Direct Evaporative Cooler Performance in Sacramento

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Indirect/direct evaporative cooler (IDEC) units were installed and monitored in six Sacramento residences with existing central air conditioning to assess the energy, demand, thermal performance, and comfort implications of IDEC cooling in the Sacramento area. IDEC retrofits were completed in September 1992. After three weeks of "shakedown" monitoring in 1992, 15 weeks of useful summer data were recorded from June 13 through September 25, 1993.

Key conclusions from the 1993 data included:

1. For three of the six sites where the existing air conditioning system was used during the 1993 test period, peak IDEC vs. air conditioner cooling demand reductions of 57-79% were monitored. The other three sites did not use air conditioning during the 1993 monitoring period.

2. Typical cooling energy savings of 60% are projected based on the monitored performance of the IDEC units and expected performance of a 10 SEER air conditioner.

3. Occupants of five of the six sites appeared satisfied with the performance of their IDEC units based on their cooling system selection. During the peak two-day hot spell (109°F and 105°F), five of the six sites relied exclusively on their evaporative cooler. The sixth site consistently maintained low indoor temperatures (about 74°F) which were difficult for the IDEC unit to achieve under high load conditions. Indoor discomfort due to high indoor relative humidity was limited to a few occasions for occupants of the five sites who relied primarily on their IDEC systems.

4. Daily water use during the 15-week monitoring period averaged 61 gallons/day, but varied considerably between sites.

5. Although monitored performance results and occupant perception were generally favorable, several factors appear essential to widespread acceptance of IDEC technology:

    a. Favorable value assessment based on utility marginal capacity and energy costs
    b. More detailed evaluation of IDEC water use vs. energy savings
    c. Proven long-term IDEC reliability
    d. HVAC contractor education.

Introduction

The Sacramento Municipal Utility District (SMUD) initiated a project in August 1992 to determine the field performance of six indirect/direct evaporative cooler units in the Sacramento area. The units were installed in September 1992 in parallel with the existing mechanical air conditioning systems. Each room of the house had a supply duct and a ceiling up-duct for discharging room air into the attic. Numerous HVAC contractor call-backs were necessary due to contractor unfamiliarity with the IDEC technology. Three weeks of performance monitoring occurred in 1992 and 15 weeks in 1993. Occupants were allowed full freedom in selecting which cooling system and IDEC operating mode they preferred.

Evaporative coolers consume much less energy than compressor-based cooling systems, since only fans and pumps are needed to provide evaporatively cooled air to the house. Direct evaporative coolers, commonly known as swamp coolers, draw outdoor air through a continually wetted media and deliver nearly saturated air to the indoor space. Supply air temperatures rise with outdoor wet bulb, often resulting in uncomfortable indoor conditions. IDEC units provide increased cooling capacity and indoor comfort by combining an "indirect" cooling stage prior to the direct evaporative stage. The indirect stage utilizes a heat exchanger, fan, and pump to evaporate water in one flow path for outdoor air precooking in the second flow path. The precooled air enters the direct evaporative stage and is further cooled, but with less moisture addition than a direct evaporative unit. The IDEC units evaluated in this project provided four distinct operating modes: low- and high-speed direct evaporative, and low- and high-speed indirect/direct evaporative.

Prior studies (Feustel et al. 1992 and Huang et al. 1992) have evaluated IDEC potential as an alternative to residential air conditioning. IDEC viability is highest in dry southwestern climates where indoor comfort is less affected by the addition of moisture to the supply air.

This paper discusses the following aspects of the monitoring project:

1. Field installations and monitoring equipment
2. Data collection and analysis
3. 1993 monitoring results
4. Conclusions.

Monitoring Methodology

The primary project objective was to determine IDEC field performance in residential applications with existing central air conditioning. IDEC cooling capacity, energy use, demand, and water use were the primary data points of interest; air conditioner monitoring was limited to energy use and demand.

Field Installations and Equipment

Each of the six sites had the following monitoring equipment installed:

1. Portable remote data logger
2. Modem with dedicated phone line (for data downloading)
3. Power monitors for IDEC and air conditioner energy use
4. Water flow meter for IDEC water use
5. Relative humidity sensors for indoor and outdoor relative humidity
6. Four shielded Type T thermocouples monitoring indoor temperature (thermostat and second location), outdoor air, and IDEC supply air.

Monitoring system installations were completed between September 17 and September 29, 1992. Low- and high-speed air flow measurements at each supply register were performed at each site on two or three separate occasions during 1993 using a flow hood (accuracy ±5%). A portable relative humidity temperature sensor (accuracy of ±2% relative humidity and ±.54°F) was used to spot-check data logger sensor calibrations at each visit. No static pressure or duct leakage measurements were taken during the project.

Table 1 provides a general characterization of the six houses, and Table 2 specifies the IDEC configuration and both design and measured air flow. Supply air flow values in Table 2 represent an average of the multiple readings taken during the course of the project. Design air flow exceeded monitored air flow for all six houses. Possible explanations include duct leakage (although visual inspection ruled out any catastrophic leakage) and underestimated static pressure losses from the barometric damper.

Single inlet units comprised a direct cooling module (direct evaporative media and a 3/4 hp supply air fan) and an indirect cooling module (heat exchanger with 1/5 hp prop fan). Higher capacity dual inlet units comprised a similar direct cooling module (with a larger 1 hp supply air fan) and two 1/5 hp indirect cooling modules (ICMs). ICM demand was monitored at 0.36 kW; supply fan demand varied by site based on total air flow and delivery system static pressure. During the project, manufacturer's representatives visited each of the sites at least once to insure reliable operation.

Data Reporting

Field data, averaged and recorded by the data logger in 15-minute intervals, were retrieved twice a week via modem, reviewed for missing data, and then stored for weekly data processing. Weekly reports were generated and sent to the utility project manager in a timely manner. The reports included time series plots of key temperatures (indoor, outdoor, and supply air temperature); IDEC and AC 15-minute demand; and a summary table presenting key operating characteristics for each day of the week.

Table 1. House Descriptions

Residence	House ft^2	System Size & Type	IDEC Inlet Configuration
Site 1	1400	3 ton Split Gas/AC	Double
Site 2	884	3 ton Package HP	Single
Site 3	1230	3 ton Package AC	Single
Site 4	1700	3 ton Package Gas/AC	Double
Site 5	1058	3 ton Package HP	Single
Site 6	1860	3 ton Split Gas/AC	Double

Table 2. IDEC Air Flow

Residence	Design cfm	Measured cfm High	Measured cfm Low
Site 1	3780	2690	1370
Site 2	2730	1790	885
Site 3	2730	2190	1270
Site 4	3780	3100	2020
Site 5	2730	2280	1260
Site 6	3780	2830	1800

Three key IDEC performance descriptors presented in the reports were calculated as follows in Equations 1-3:

$$Qc = 1.08 \times Cfm \times (Tin - Tsup) \quad (1)$$

where Qc = IDEC cooling delivered (Btu/hour)
Tin = indoor temperature (°F)
Tsup = supply air temperature (°F)
Cfm = total supply register air flow.

$$Eff(\%) = 100 \times (Tdb - Tsup) / (Tdb - Twb) \quad (2)$$

where Eff = IDEC effectiveness
Tdb = outdoor dry bulb (°F)
Tsup = supply air temperature (°F)
Twb = outdoor wet bulb (°F).

$$Ieer = Qc / Ip \quad (3)$$

where Ieer = IDEC EER (Btu/watt-hr)
Qc = IDEC cooling (Equation 1)
Ip = IDEC unit demand (watts).

Initially, IDEC cooling was calculated as shown in Equation 1; however, it was soon determined that 15-minute averaged data did not provide enough resolution when the IDEC unit cycled or the occupant selected a different operating mode during a 15-minute interval. The six data loggers were reprogrammed and individually recalibrated to generate an integrated cooling delivery for each 15-minute interval. This integration scheme significantly improved the accuracy of the cooling delivery calculation by reducing the "delivered cooling" calculation interval from 15 minutes to between 30 and 60 seconds.

Monitoring Results

Factors Affecting IDEC Performance

Higher IDEC supply air temperatures relative to mechanical air conditioning (typically 70°F vs. 55°F) suggest maximizing supply air flow to maintain comfort. Maximizing supply air flow by minimizing system static pressure, and insuring ideal air and water flow in the evaporative modules, are essential to good IDEC performance. Tightly sealed ducts are also important in delivering as much conditioned air to the space as possible.

IDEC cooling capacity must be distinguished from mechanical air conditioning cooling capacity since the IDEC system is 100% outdoor air, and conventional air conditioning recirculates and cools house air. Air conditioner cooling capacity is sensitive to outdoor temperature, yet the AC system will always maintain a

20-30°F supply-to-return temperature differential. The 100% outdoor air IDEC system is totally decoupled from indoor conditions and supplies air at a temperature dependent upon outdoor wet bulb temperature and system effectiveness. Under high cooling load conditions, when both outdoor dry and wet bulb temperatures are rising, the IDEC supply air temperature increases and could (depending upon indoor thermostat setpoint) exceed indoor temperature. Low outdoor wet bulb conditions (such as in the early morning) are much more favorable IDEC operating conditions, since supply air temperatures would typically be much lower than indoor air temperatures. The impact on EER is significant; for a fixed 80°F indoor temperature, the lower early morning condition would result in efficiencies 300% higher than at mid-day. For example, IDEC operation at a 65°F 6 AM outdoor wet bulb temperature would provide three times the delivered cooling than operation at a 75°F mid-day wet bulb temperature (assuming 100% effectiveness).

IDEC Performance Summary

This section summarizes the cooling loads, operating characteristics, and efficiency of each of the six sites during the 15-week monitoring period. Table 3 presents key IDEC operating data and Table 4 presents energy and demand characteristics. (For Site 6, Tables 3 and 4 include only week 5-11 data, as discussed in the Site Performance Summary section.) For the months of June through September, the National Weather Service site in Sacramento recorded 1379 Cooling Degree Days (base 65°F), about 13% higher than normal.

Table 3 IDEC cooling as calculated by the data logger integration scheme does not account for the IDEC benefits of:

1. Elimination of infiltration during IDEC operation due to house pressurization
2. Elimination of latent AC cooling loads, typically 20% for dry climates (ASHRAE 1993)
3. Reduced ceiling heat gains due to exhausting conditioned house air to the attic

Monitored IDEC cooling at the six sites ranged from 4.4 to 16.1 MBtus; average daily IDEC operation ranged from 2.3 to 7.8 hours per day. Average monitored indoor temperatures during IDEC operation ranged from 74.2°F to 80.3°F with four sites clustered between 76.7°F and 77.9°F. The low average indoor setpoint at Site 5 reduced the calculated IDEC cooling, as discussed in the previous section.

Monitored average cooling capacities, calculated by dividing total cooling delivered by operating hours, for the full fifteen-week period ranged from 8.5 to 27.9 kBtu/hr. Low Site 5 thermostat setpoints resulted in low monitored average cooling capacity. “Adjusted” average cooling capacity is estimated to raise the monitored value by 25% to account for the above-mentioned IDEC benefits of infiltration elimination, no latent cooling, and reduced ceiling heat gains. The adjusted capacity allows for a better prediction of the amount of cooling a mechanical air conditioner would need to provide.

Average effectiveness reported in Table 3 is for all data when there was continuous operation over the 15-minute interval. Average effectiveness for the six sites, weighted by delivered cooling, was calculated to be 99%. Although this value is lower than typical manufacturers’ specifications (roughly 105-110%), it suggests acceptable field operation.

Monitored full-season EERs ranged from 10.3 to 28.3 with a cooling weighted average of 18.0. Adjusted EERs, increased by 25%, ranged from 12.9 to 35.4 with a weighted average of 22.5. Considering that a 10 SEER air conditioner will operate closer to its EER rating (≈ 9) in the hot Sacramento climate, IDEC efficiency improvements of roughly 150% are projected. This estimated 60% savings is comparable to the 70% Sacramento simulation-based savings presented in a prior study (Huang et al. 1992).

Monitored water use for the 15 weeks ranged from 1,314 to 19,592 gallons with an average use of 61 gallons per day. Although not monitored for a full cooling season, the average site water use of 6400 gallons is consistent with the 6600 gallons per year simulation projection for Sacramento retrofit applications (Huang et al. 1992). The low Site 5 water use (≈ 2 gallons/operating hour) is curious; however, if true, it indicates little or no bleed of sump water and a potentially low evaporation rate, consistent with the lowest effectiveness among the six sites. Single inlet unit water use ranged from 2 to 10 gallons/hour and dual inlet unit use from 8 to 24. The very high Site 1 water use appears to indicate excessive bleed-off.

Table 4 shows the impact of increasing outdoor temperature on IDEC EER for all monitoring data. As expected, EERs fell with increasing outdoor dry bulb (and wet bulb) temperature, since cooling capacities decrease and IDEC power is constant. Site 5 EERs were low due to low indoor setpoints and possibly low evaporation rates. For all but Sites 4 and 6, the average IDEC EER in Table 3 exceeds the 90-95°F EER in Table 4, indicating significant operation at lower outdoor temperatures. Of the four sites, between 46 and 51% of IDEC energy use

Table 3. IDEC System Performance Characteristics

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6@
IDEC Cooling (kBtu)	16051	9877	12443	4794	5287	4361
IDEC Operating Hours	824	667	708	242	620	156
Average IDEC Capacity (kBtu/hr)	19.5	14.8	17.6	19.8	8.5	27.9
Adjusted Avg Capacity (kBtu/hr)	24.3	18.5	22.0	24.8	10.7	34.9
Average Operating Hours/Day	7.8	6.4	6.7	2.3	5.9	3.2
Average Indoor Temperature**	77.2	77.6	76.7	77.9	74.2	80.3
Average Effectiveness	95%	98%	110%	100%	91%	92%
Average IDEC EER	14.1	28.3	22.0	18.2	10.3	16.5
Adjusted Average IDEC EER*	17.6	35.4	27.5	22.8	12.9	20.6
Total Water Use (gallons)	19592	4363	7112	2992	1314	3058
Water Use/Operating Hour	24	7	10	12	2	8

"*" 1.25 x monitored data
"**" During IDEC operation
"@" Data for weeks 5-11 only

Table 4. Monitored Average IDEC EER vs. Outdoor Temperature

Outdoor Temperature	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6@
90-95°F	12.9	27.5	18.3	20.5	7.5	16.5
95-100°F	11.1	24.5	16.5	17.0	5.7	15.1
100-105°F	10.0	22.5	15.3	16.4	2.0	14.9
> 105°F	8.1	16.4	14.8	13.1	3.4	12.6

"@" Data for weeks 5-11 only.

occurred below 90°F outdoor dry bulb, where IDEC efficiencies are higher. Site 6 monitoring indicated 70% of IDEC cooling energy use occurred at outdoor temperatures above 90°F; therefore, full-season EER was less than for the 90-95 "F bin. Table 4 values have not been increased by 25% to reflect the IDEC cooling benefits of reduced infiltration, reduced ceiling heat gains, and elimination of latent cooling loads.

Table5 summarizes the energy and demand characteristics of the six sites during the full 15-week 1993 monitoring period. Peak 15-minute IDEC demand ranged from 0.61 kW to 1.91 kW. Average single inlet unit peak (and average) demand was 0.95 kW (0.71 kW); average dual inlet unit peak (and average) demand was 1.66 kW (1.38 kW). Three of the sites used no air conditioning during the full monitoring period; the remaining three

Table 5. IDEC System Demand and Energy Characteristics

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
IDEC Peak kW	1.51	0.61	1.11	1.55	1.12	1.91
IDEC Average kW	1.38	0.52	0.80	1.09	0.82	1.67
Air Conditioner Peak kW	0.20	0.02	0.26	7.28	3.53	4.48
% Peak kW Reduction	n/a	n/a	n/a	79%	68%	57%
IDEC kWh	1138	349	565	264	511	606
Air Conditioner kWh	42	23	66	110	779	449
% IDEC kWh (of total)	96%	94%	90%	71%	39%	57%

sites demonstrated on-peak demand reductions (IDEC vs. mechanical air conditioning) of 57-78%. Seventy percent of the cooling energy consumed at the six sites during the 1993 monitoring period was by the IDEC units.

Peak Weather Performance

The peak two-day hot spell for the 1993 Sacramento cooling season occurred on August 1 and 2 (a Sunday and Monday). National Weather Service Sacramento downtown high temperatures were 109°F and 105°F, respectively, with low temperatures of 71°F and 76°F. Federal Aviation Administration Executive Airport weather data and relative humidity for the two days suggests peak humidity ratios (pounds of moisture per pound of dry air) of approximately 0.011, or about 30% higher than the ASHRAE Sacramento 1% design condition of 101°F dry bulb and 70°F wet bulb (0.085 humidity ratio). These extreme conditions provided an excellent opportunity to evaluate "worst case" Sacramento IDEC performance on a utility peak load day.

Table 6 presents monitored IDEC and air conditioner demand for the six sites over the 1-9 PM utility peak period. Average diversified IDEC demand for the six sites was 0.78 kW. Since there was no air conditioner control group as part of this program, it is difficult to project diversified air conditioner demand data for this two-day period. On August 1, Site 5 relied almost exclusively on mechanical air conditioning with an average 1-9 PM cooling demand of 3.36 kW; however, data are not sufficient to present a valid diversified demand comparison.

Of the six sites, five relied exclusively on the IDEC system for cooling, indicating apparent satisfaction with IDEC comfort. During the two-day period when outdoor

Table 6. Average 1-9 PM Cooling Demand (kW) for August 1 and 2

Outdoor Temperature	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
August 1st - IDEC	1.43	0.53	0.96	0.57	0.02	0.76
August 1st - AC	0.00	0.00	0.00	0.00	3.36	0.00
August 2nd - IDEC	1.40	0.54	0.64	0.65	0.48	1.33
August 2nd - AC	0.00	0.00	0.00	0.00	1.79	0.00

temperatures exceeded 100°F, supply air temperatures averaged 73.7°F and 76.0°F, respectively. Higher peak wet bulb temperatures (76. 6°F and 76.9°F, respectively) during this more humid period were responsible for the higher-than-typical supply air temperatures, which normally averaged about 70°F at mid-day. A brief description of operation at two of the sites follows:

Site 5— The IDEC unit was operated alternately with the air conditioner during the two-day hot spell. On the morning of August 1 the IDEC unit was operated in low-speed, two-stage mode from 4 to 7 AM. At approximately 10 AM, with indoor temperature at about 73.5°F, the IDEC was shut off, and the air conditioner was turned on and ran without cycling until 11 PM. Interestingly, peak indoor temperature rose during air conditioner operation from 73.5°F to about 78°F. On August 2, the IDEC unit was operated in high-speed, two-stage mode from 8 AM to 2 PM, during which time indoor temperature rose from about 74°F to 78°F. The occupants then switched to air conditioning and maintained the indoor temperature at about 78°F until 7 PM. From 7 to 9 PM the IDEC unit was operated in high-speed, two-stage mode and indoor temperature fell from 79 to 77°F. The air conditioner was then turned on and operated until midnight. Based on their control of the cooling systems, it is apparent that the occupants were unable to maintain comfort exclusively with the IDEC system. Peak air conditioner and IDEC demand during the two-day period was approximately 3.5 and 1.0 kW, respectively. Figures 1 and 2 show Site 5 temperature and demand profiles for the two days.

Site 6— The IDEC unit was operated on high-speed, two-stage mode both days; on August 1 the unit cycled from noon to midnight while maintaining an indoor setpoint of about 82°F. On August 2, the unit was not operated until about 1 PM when indoor temperatures had risen to nearly 85°F. The unit ran without cycling until 7 PM, when the indoor temperature was reduced to just over 80°F. The unit was off for approximately 1 hour and then cycled for 3 hours. The IDEC unit appeared to provide adequate cooling on both days. Figures 3 and 4 show Site 6 temperature and demand profiles for the two days.

Site Performance Summary

Brief site-by-site descriptions of overall IDEC system performance follows. Reporting of occupant perceptions is based on informal discussions during site visits.

Site l—The Site 1 dual-inlet IDEC unit provided the most consistent trouble-free operation from the start of the project; the only shortcoming was very high water use (24 gallons per operating hour). As the highest IDEC cooling user of the six sites, the cost savings associated with evaporative cooling became clear during the summer. The residents relied exclusively on their IDEC system for cooling. The overall monitored EER of 14.1 was below average; higher-than-average supply air temperatures and continuous mid-day operation reduced efficiency. The residents relied almost exclusively on high-speed, two-stage operation with the "average" demand of all operating hours being 91% of the peak recorded Site 1 IDEC demand. One complaint expressed by the homeowners was a "fishy smell" during the first half hour of each IDEC operating cycle.

Site 2— The Site 2 single-inlet IDEC unit registered the highest average EER (28.3) of the six sites, and no supplemental air conditioning operation occurred. Peak high-speed, two-stage demand was nearly 45% less than the other single inlet IDEC units, largely due to the more compact duct system layout and the 20% lower measured supply air flow (1790 vs. 2235 cfm). (The "cubed law" fan power vs. cfm relationship dictates that for a given static pressure a 20% reduction in cfm will reduce fan power by nearly half.) The small size of the house allowed the original factory motor setting to provide sufficient air flow; all five of the other houses required motor belt adjustments to provide sufficient air flow to maintain comfort. The occupants expressed satisfaction with the cooling performance and reduced cooling costs of their IDEC system.

Site 3— The Site 3 single-inlet IDEC unit recorded the second highest EER and total IDEC cooling delivery with no supplemental conventional air conditioning during the 15-week period. The unit performed well on the peak hot spell and maintained indoor setpoint. The occupants typically utilized the high-speed, two-stage mode during the day and then switched to low-speed, two-stage mode at night. The occupants appeared pleased with both IDEC comfort and reduced cooling costs.

Site 4— The Site 4 dual-inlet IDEC unit operated well (after a malfunctioning barometric damper was fixed in week 2) and recorded the highest EER (18.2) and air flow (3100 cfm) of any dual-inlet unit. After week 2, the occupants did not use their conventional air conditioner for the remainder of the summer. The occupants were the most adventurous in experimenting with the various IDEC operating modes, although IDEC cooling energy use was the lowest of the six sites. The "average" IDEC demand for all operating hours was 70% of the peak monitored Site 4 IDEC demand, the lowest percentage among the six sites. The low percentage indicates considerable operation other than high-speed two-stage and contrasts with the 91% value for Site 1. Occupants were very satisfied with IDEC system performance and operating cost savings.

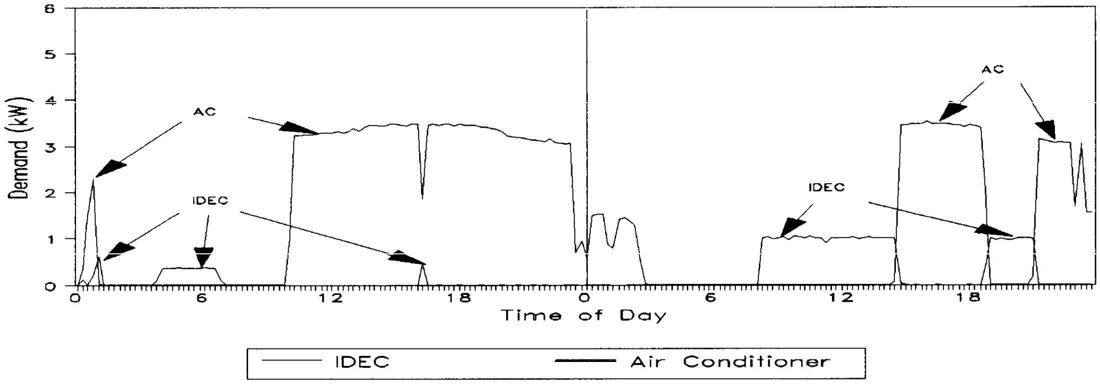

Figure 1. Site 5 Demand (8/1-8/2)

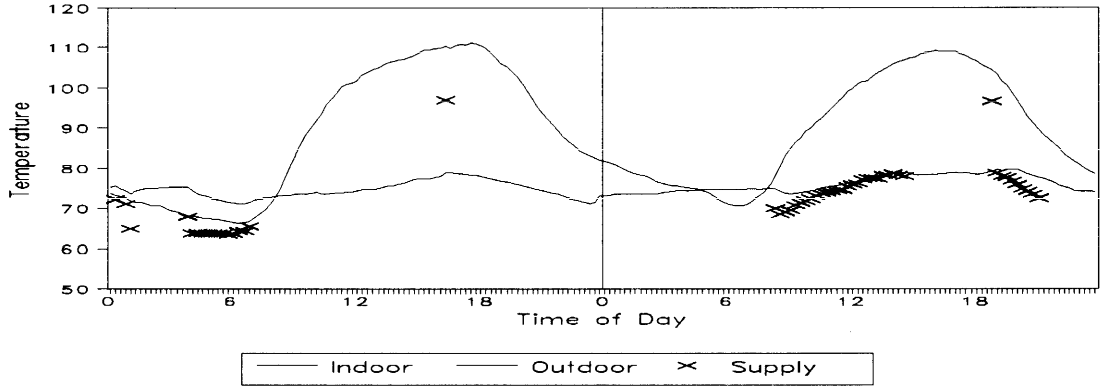

Figure 2. Site 5 Temperature (8/1-8/2)

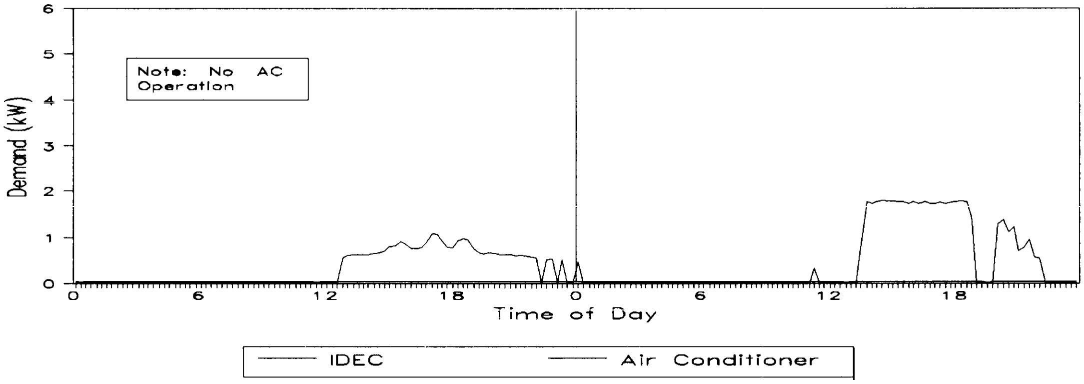

Figure 3. Site 6 Demand (8/1-8/2)

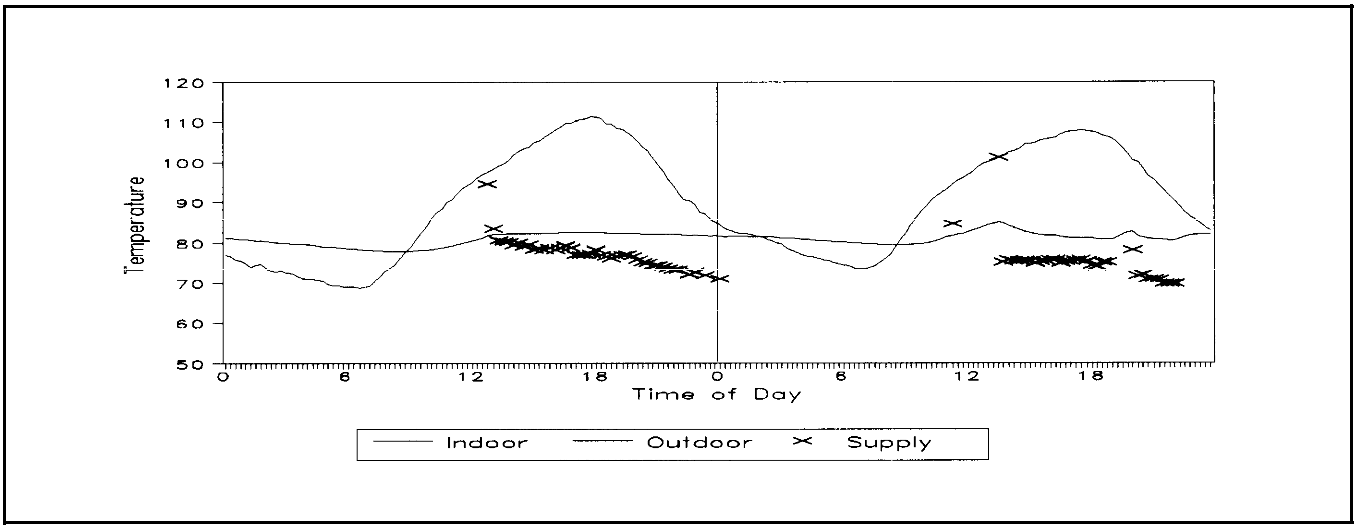

Figure 4. Site 6 Temperature (8/1-5/2)

Site 5— The Site 5 single-inlet unit was unable to maintain comfort on a consistent basis given the occupants' comfort requirements. The occupants would often start the day with IDEC cooling and then switch to their mechanical air conditioner. They experienced some problems with the thermostat and with the living room supply air register which would frequently close. Given the relatively low effectiveness and the occupants' occasional complaint of high indoor humidity, it is possible the indirect module was not achieving desired performance, since low indirect module effectiveness would result in more moisture addition at the direct module. Upon decommissioning of the site, the direct-stage sump water was found to be relatively dirty, suggesting a small bleed rate. Site 5 monitoring was very useful in pointing out IDEC limitations for homeowners who prefer cool and relatively dry indoor conditions.

Site 6— The Site 6 dual-inlet IDEC unit was plagued by problems at the beginning and end of the 1993 monitoring season, resulting in a low full-season EER of 9.7. However, during weeks 5-11 the average EER consistently ranged from 15 to over 20. The 1.91 kW peak demand for the IDEC unit was about 25% higher than for the other two dual-inlet units, probably due to the larger house size and resulting greater duct static pressure. During the 7 weeks when the unit was operating properly, the occupants relied exclusively on their IDEC unit. Operation during Weeks 12-15 was affected by the homeowners' attempt to reduce the amount of "bleed" water draining to their back yard. By inadvertently reducing water flow to the evaporative media (as well as the bleed line), Site 6 IDEC performance was significantly degraded during the last four weeks of monitoring. Week 5-11 data presented in this report (see Tables 3 and 4) should be considered more typical of how the unit should have performed during the full monitoring period.

Indoor Comfort Conditions

Figure 5 shows a distribution plot of indoor temperature and coincident relative humidity for Site 1 for all 15-minute intervals when the IDEC unit was operating. The area of each circle is proportional to the frequency that the event occurred. Also included on the plots are summer indoor comfort envelopes from ASHRAE (ASHRAE 1993) and an evaporative cooling handbook (Watt 1986). Much of the data falls outside of the defined comfort envelopes; however, a fairly typical thermostat setpoint of 78°F and relative humidity of 50% would also fall outside both comfort envelopes, suggesting that they are overly conservative.

Useful information on IDEC indoor relative humidity impact came from Site 5 with the frequent switching from IDEC to mechanical cooling. A review of representative data suggests that average indoor relative humidities increase by approximately 15% when cooling is switched from mechanical cooling to IDEC.

Conclusions

Key conclusions from the 1993 monitoring data include:

1. Measured air flow readings were lower than specified. Lower than design air flows are common due to unaccounted-for static pressure within the delivery or attic exhaust systems. Both single and dual inlet unit supply air flows averaged 76% of the design target. Maximizing air flow is critical for IDEC systems due to higher supply air temperatures relative to mechanical air conditioning.

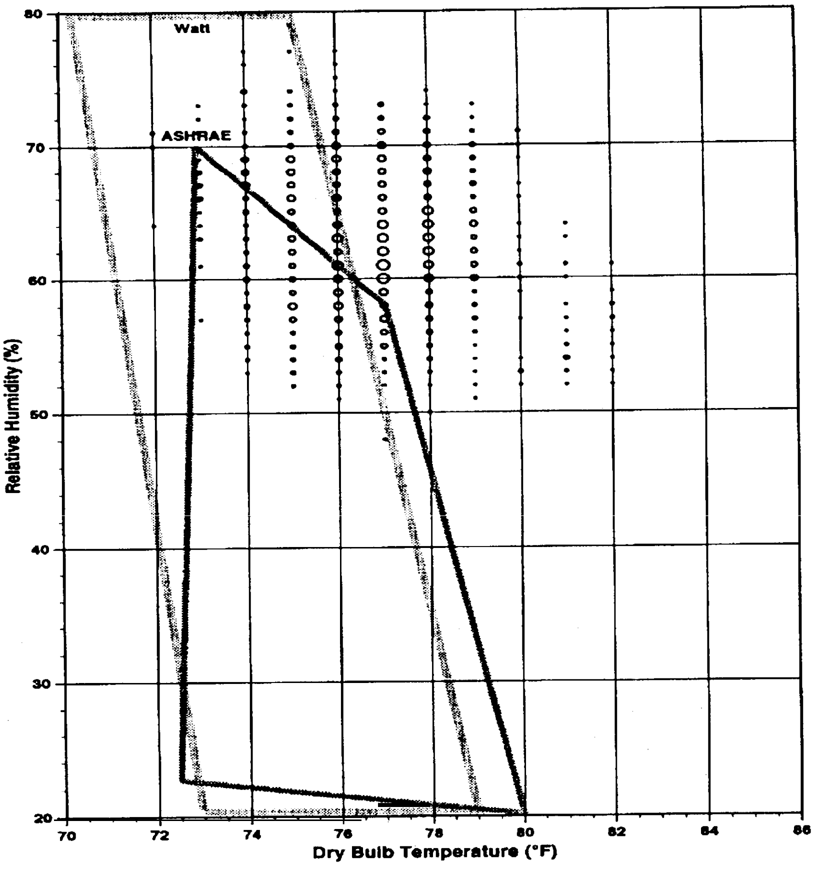

Figure 5. Site 5 Indoor Conditions During IDEC Operation

2. IDEC peak demand is independent of outdoor temperature and significantly lower than conventional air conditioners. Peak monitored single and dual inlet IDEC demand was 1.12 and 1.91 kW, respectively. Peak monitored AC demands of the three sites where air conditioners were operated were 3.53, 4.48, and 7.28 kW. Monitored diversified IDEC demand (average from 1-9 PM) for the six sites during the peak weather spell was 0.78 kW.

3. IDEC system efficiencies were about 150% higher vs. a 10 SEER AC on a full-season basis. Adjusted IDEC EERs of about 22.5 were about 150% higher than the expected Sacramento seasonal performance of a 10 SEER air conditioner, indicating 60% energy savings. (The full-season performance of a 10 SEER air conditioner in Sacramento is approximately equal to its 95°F EER rating of about 9.0.)

4. Occupants were satisfied with IDEC indoor comfort. Although there was no formal survey, informal discussions with homeowners indicated general satisfaction with IDEC comfort levels. (Site 5 experienced humidity discomfort and would frequently switch between IDEC and AC cooling.) Five of the six sites relied exclusively on their IDEC systems for cooling during the peak weather spell, although only three systems could maintain the indoor setpoint.

5. System operating efficiency was sensitive to occupant control. IDEC cooling capacity and efficiency are proportional to the indoor-to-supply -air-temperature difference. The most favorable monitored performance occurred with higher indoor temperatures and low outdoor wet bulb temperatures. Night pre-cooling might be an attractive IDEC strategy.

6. System water use is an important issue. A cost-benefit assessment of IDEC energy/demand savings relative to water use should be performed. IDEC water use for the six units was highly variable, suggesting the need for a more reliable bleed control. Average monitored summer water use of 61 gallons per day is significant and needs to be evaluated in conjunction with IDEC energy and demand benefits.

7. IDEC technology is not fully mature. Improved technology support by manufacturers and utilities, system improvements (high efficiency or variable speed motors), and HVAC contractor education is needed to improve the field reliability and performance of IDEC systems.

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