DEVELOPMENT OF AN IMPROVED TWO-STAGE EVAPORATIVE COOLING SYSTEM

CONSULTANT REPORT

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This report cannot leave unrecognized the substantial roles of DEG Senior Engineers **Duncan Callaway** and **Eric Lee**. Eric had major responsibility for our early development work on the counterflow indirect heat exchanger that has been so central to project success. Eric also completed the complex design work associated with the roto-molded cabinet. Duncan joined DEG and the project in early 2003, and nudged/nurtured it through the

crucial steps that have made it work, including design of the indirect heat exchange plates and the water feed system. DEG President **Dave Springer** has also helped substantially with his experience from the two prior IDEC generations. It takes a team to grow an IDEC, and it has been a joy to work toward that end with these great people.

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 PIER Program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

What follows is the final report for Contract #500-98-022, entitled Development of an Advanced Indirect Heat Exchange Module, conducted by Davis Energy Group, Inc. The report is entitled Development of an Improved Two–Stage Evaporative Cooling System. This project contributes to the Buildings End-Use Energy Efficiency program.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.

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Executive Summary

Introduction

This report summarizes development by Davis Energy Group (DEG) of a third generation ("Gen 3") two-stage evaporative cooler (indirect-direct evaporative cooler or IDEC) under the California Energy Commission's Public Interest Energy Research (PIER) program. The project began in September, 1999 and was completed in November, 2003. The original project goal was to develop an improved, lower cost indirect heat exchanger for the second generation ("Gen 2") unit. After several years' work, DEG requested project changes to pursue the more aggressive goal of improving the cabinet as well as the indirect heat exchanger. The project has met or surpassed all of its original and final goals, and the end result is a unit that is substantially less expensive and more energy efficient that its predecessors.

IDEC units are "two-stage" evaporative coolers that can cool air to lower temperatures than are attainable with direct ("one-stage") evaporative coolers, and add less moisture to the indoor air. The original IDEC ("Gen 1") units designed by DEG were developed from 1992-95 with 45% match support from the Energy Commission's Energy Technologies Advancement Program (ETAP). A monitored field test showed the Gen 1 units to be six times more efficient than conventional cooling, and all users were satisfied with IDEC comfort. But with deregulation looming, manufacturing partner AdobeAir left the project in late 1995, and in late 1996 was replaced by CoolTech, a startup venture that then developed and produced the "Gen 2" unit. The Gen 2 units were similar in design to the Gen 1 units and also used AdobeAir indirect heat exchangers. However, because AdobeAir did not wish to produce the wider, custom heat exchanger used in the Gen 1 design, CoolTech was forced to use Adobe's standard heat exchanger, which was 4 inches narrower. This constraint led to a host of problems, including an efficiency drop compared to the Gen 1 units.

Objectives and Approach

In 1998, DEG proposed this PIER project to improve Gen 2 performance and lower costs by developing an improved indirect heat exchanger that would not require purchase from AdobeAir. But CoolTech ceased operations soon after the proposed project was awarded PIER funding. DEG continued development of the advanced heat exchanger, working within the constraint of the CoolTech cabinet. After substantial testing, DEG determined that to match Gen 1 performance, the unit needed a wider cabinet and a top-mounted blower in addition to the improved indirect heat exchanger. Upon DEG request, the Energy Commission granted a change in deliverables to allow DEG to improve the cabinet instead of completing Gen 2 unit field tests, and to achieve the following revised objectives:

- Improve design flexibility by developing an improved indirect heat exchanger with potential for variable assembled widths, which would allow units of many different capacities to be produced by the same manufacturing process.
- Improve design quality by eliminating adhesives in heat exchanger assembly, and by eliminating leakage and corrosion using a molded cabinet with top mount blower.

- Reduce initial cost by $300 using 1) a one-piece molded cabinet with integral blower housing and water sump, and 2) a more rapid heat exchanger fabrication process.
- Lower operating costs at least 5% by increasing evaporative effectiveness and reducing power consumption.

These revised objectives for the Gen 3 unit were consistent with the goal of the original project – to increase evaporative cooling efficiency – and required that DEG:

1. Design and fabricate both an improved indirect heat exchanger and a molded cabinet,
2. Laboratory test the unit to confirm that the new design meets performance goals, and
3. Simulate system performance in target California climates to assess market potential.

After DEG and the Energy Commission had made these project changes, the Speakman Company of Wilmington, Delaware expressed interest in manufacturing the Gen 3 IDEC unit. Speakman and DEG subsequently signed a letter of intent that will lead to a license agreement based on specified development outcomes. In a parallel effort to DEG's Gen 3 refinement, Speakman has developed a PV-powered DC drive system for the new IDEC that will be tested at an installation supported by SMUD.

DEG worked with AVC of Torrance, CA, an inline thermoformer, to continue development of the promising counterflow indirect heat exchanger by using a rapid production process for the heat exchange plates. Produced on custom tooling, the new plates have molded-in spacers, snaps, and air diverters that provide structure and define airflow paths in the built-up heat exchanger. Complete indirect heat exchangers can now be assembled quickly using snapping and crimping procedures, without messy adhesives, and represent a major step forward in indirect heat exchanger construction.

DEG also worked with Scribner Plastics of Rancho Cordova, CA to develop a "rotationally-molded" plastic cabinet that houses all components, including the new indirect heat exchanger. The one-piece cabinet replaces more than a dozen sheet metal parts that had been used to assemble the Gen 2 cabinets. In addition to reducing materials and labor costs, this polymeric cabinet eliminates corrosion. Like the prior generations, the new IDEC incorporates an "electronically-commutated motor" (ECM) and variable-speed controls that maximize energy efficiency and enable the gradual and quiet speed changes that have been very popular with IDEC users.

After basic development of the plate and cabinet components, DEG developed and tested the water distribution components that are crucial to uniform wetting of heat exchanger surfaces. DEG then conducted formal performance tests of the completed IDEC unit that were certified by the Lawrence Berkeley National Laboratory. This test unit outperformed both the Gen 1 and Gen 2 designs and significantly exceeded project performance goals. Varying inversely with blower speed, evaporative effectiveness ranged from 109% to 116% and the energy efficiency ratio (EER) ranged from 40 to 136. These results represent a 28 to 53% improvement in EER over Gen 1 and Gen 2 performance.

DEG used the MICROPAS two-stage evaporative cooler model developed in the ETAP project, in conjunction with new test data, to compare IDEC and conventional cooling system performance for two building types in eight California climate zones. The analyses estimated 89 to 95% IDEC annual energy savings accompanied by 80 to 89% peak demand savings.

Project Outcomes

The advances made in this project contribute significantly to the marketability of the Gen 3 unit. The improvements in effectiveness, which reduce the unit's supply air temperature, translate directly to a reduction in the supply air volume required to reach a given room temperature set point. Consequently, the Gen 3 unit is not only more energy efficient than its predecessors (because less blower motor energy is needed), it provides greater user comfort by adding less total moisture to the air. Regarding product economics, the improved indirect heat exchanger manufacturing process and simplified housing will reduce manufacturing costs by over $380 per unit. These project outcomes—enhanced user comfort, improved energy efficiency, and reduced manufacturing costs—suggest that the Gen 3 IDEC unit should perform well in the marketplace.

Benefits to California

The potential benefits to California and other regions with suitable climates are encouraging. The installation of 10,000 IDEC units in a retrofit market could reduce peak demand by as much as 28 MW, and could save 15 GWh per year. These reductions could take the some of the most polluting peaker power plants off-line, and contribute significantly to California's commitment to reducing greenhouse gas emissions.

Conclusions and Recommendations

IDEC units deliver 100% outdoor air, and therefore have enormous potential in applications where indoor air quality is especially important. Modular classrooms, for which IDEC capacity is well suited, represent an especially attractive application for this reason.

Two additions to the Gen 3 design could further expand the IDEC market. First, the incorporation of a gas-fired hydronic heating system would allow users to install one system to satisfy heating and cooling requirements. Second, a vapor compression system that positions an evaporator in front of the direct stage and uses indirect stage exhaust air to cool the condenser would expand the system's applicability to regions (mostly outside California) where IDEC capacity is limited by high humidity. An especially attractive market for this product would be in parts of the Southwest where the warm monsoon season punctuates otherwise hot and dry summers.

Other next steps recommended for continuing PIER support include:

- Conduct field test and demonstration projects that verify durability and enhance visibility
- Develop an automated heat exchanger production process that further reduces costs

- Develop additional components that broaden IDEC marketability, including housings for alternate installations, optimized indirect plates, upgraded controls, and an internal drain valve system
- Develop a smaller IDEC that competes with room air conditioners.

Abstract

Davis Energy Group has developed a "Generation 3" indirect-direct evaporative cooler (IDEC) with support from the California Energy Commission's PIER program. The unit combines advances in airflow configuration with manufacturing improvements to reduce costs and improve efficiency and reliability. Like earlier generations, the new IDEC uses a highly efficient electronically commutated motor and electronic controls. The system features the following improvements:

- A low pressure drop counterflow indirect heat exchanger that pre-cools secondary air and is capable of effectiveness values greater than 70%.
- Advanced heat exchanger plates that are modular and manufactured cost-effectively on an inline thermoformer.
- A leak-proof rotationally molded cabinet with integral top-mount blower and underside water reservoir.
- A reliable, low-energy spray-less water distribution system.

Laboratory testing, supervised by Lawrence Berkeley National Laboratory, demonstrates that this new IDEC unit performs with total effectiveness ranging from 109% and 116%, varying inversely with blower speed. The test unit outperformed both prior generations, thereby exceeding project performance goals. Measured energy efficiency ratios (EER) ranged from 40 to 136, again varying inversely with blower speed. Full year performance simulations based on the test data indicate 89 to 95% IDEC annual energy savings and 80 to 89% peak demand reduction for typical California applications.

1.0 Introduction

1.1 Background and Overview

1.1.1. Potential Value

Two-stage evaporative cooling units can provide necessary cooling capacity and comfort with a fraction of the energy required for traditional vapor compression cooling (for a more detailed review of evaporative cooling technologies and markets, see Attachment 1). Widespread use of two-stage evaporative cooling technology could significantly reduce California's peak electricity demand, thereby improving the quality and reliability of our electricity system.

However, high manufacturing costs and relatively poor reliability have so far prevented two-stage evaporative cooling technology from becoming a viable alternative to vapor compression cooling. The indirect-direct evaporative cooling (IDEC) technology funded under this project promises to narrow the cost gap by utilizing an inline thermoforming process to manufacture the indirect stage plates, and by housing the unit in a low-cost, rotationally molded plastic cabinet that includes a top-mounted blower. This cabinet will greatly enhance the reliability of the unit by eliminating damaging leaks and corrosion.

Through innovations in the airflow layout, performance of this new IDEC design is significantly improved over previous two-stage evaporative cooling technology. This improvement should broaden the market for this technology by lowering operating costs and reducing moisture addition to indoor air.

1.1.2. Prior IDEC history

The original IDEC (Gen I) units designed by Davis Energy Group (DEG) were developed with 45% match support from the California Energy Commission's former Energy Technologies Advancement Program (ETAP). Gen 1 IDEC units fabricated in 1994 by subcontractor AdobeAir showed remarkable performance in the field. Over a two-month "hot summer" monitoring period in 1994, the average "equivalent" SEER for six field units was 59, six times higher than SEERs for new conventional cooling systems. All field-test IDEC owners virtually stopped using conventional systems and relied on their IDEC units.

However, with deregulation looming, AdobeAir decided not to manufacture and market the IDEC, despite its effective performance. They believed that production costs would limit its marketability without utility incentives, which they no longer expected to be available. When potential new manufacturer CoolTech requested, AdobeAir agreed to continue supplying indirect heat exchangers, but only in the 20" width used in their own two-stage evaporative cooler product (which uses two indirect heat exchangers placed side-by-side), rather than the 24" width they had custom-assembled for the field test units. Since the "Gen 1" units were relatively large, with a 26" x 30" footprint, DEG and CoolTech decided to develop a second generation IDEC. The new design would provide easier service access in addition to a smaller cabinet.

The resulting "Gen 2" cabinet width was reduced to 22" to house the narrower 20" heat exchanger. This design facilitated placement between standard framing members on 24" centers. But subsequent test data showed that the 20" face width adversely affected IDEC performance by 1) reducing the supply air quantity and 2) increasing required blower energy. Based on laboratory test results from AdobeAir in 1994 and PG&E in 1998 (see Appendix A), this double penalty substantially reduced Gen 2 performance compared to the Gen 1 units. (See results of the IDEC User Survey, Appendix B, for a comparison of customer satisfaction between the two units.)

1.2. Project Objectives

The original project objective was to develop an improved, lower cost indirect heat exchanger for the Gen 2 unit. However, after several years' work we determined that the narrow Gen 2 cabinet was too constraining. With Energy Commission support, we then pursued the more aggressive objective of improving both the indirect heat exchanger and the cabinet.

1.2.1. Original Project Objectives

When the project was proposed and funded in 1998, CoolTech was still in business and the expressed project goal was to develop a better indirect heat exchanger that CoolTech could manufacture. With project success, CoolTech would no longer need to buy indirect heat exchangers from AdobeAir, a competing firm.

However, soon after the project began, CoolTech ceased operations and time passed as DEG sought an alternate manufacturer. DEG subsequently signed an R&D agreement with Des Champs Technologies (DCT) of Natural Bridge, VA to complete development of the advanced heat exchanger. Both parties anticipated that DCT would manufacture the IDEC unit, in the Gen 2 configuration, after project completion. DCT expressed particular interest in marketing IDEC to the modular classroom industry, where IDEC's 100% outdoor air configuration is attractive in light of indoor air quality concerns. But after a year and a half of DCT project participation, new DCT management decided to drop out of the project.

1.2.2. Final Project Objectives

After DCT's departure, DEG took a hard look at IDEC status and determined that a viable IDEC product should have the following features:

a. Wider face area to regain Gen 1 efficiencies
b. A top blower design to prevent water damage to the blower motor
c. A molded cabinet to reduce cost and eliminate cabinet corrosion
d. Indirect heat exchange plates from an "in-line" process to reduce costs

DEG presented project status to the Energy Commission with three alternatives:

1. Increase funding to allow development of all four of these features
2. Maintain remaining funding to allow development of the first two features
3. Project termination

When the Energy Commission selected the second option (thereby wisely choosing to save the IDEC technology), DEG decided to invest additional cost match funds by completing the project with all four of the desirable features. Thus, the final project objectives were as follows, segregated into technical and economic objectives:

Technical Objectives. The major technical objective of the project was to design, develop, and test an indirect-direct evaporative cooler with the following improvements:

1. Design flexibility: heat exchanger design tailored for the vertical unit configuration, and allowing assembly with varying numbers of plates to provide a range of cooling capacities
2. Quality: eliminate manual gluing in plate assembly; improve leakage protection and corrosion resistance with molded plastic cabinet
3. Higher efficiency: improve water distribution for better wetting of evaporative media, resulting in at least a 10% increase in indirect evaporative efficiency, reduce air velocity with wider heat exchanger, improve plate design to reduce pressure drop

Economic Objectives. The major economic objectives of the project were to develop an improved indirect –direct evaporative cooler that provides the following improvements:

1. Initial cost: Reduce product cost by 30% compared to an $1100 base case: develop low cost "in-line" plate thermoforming process, develop one-piece molded cabinet incorporating blower housing and sump to reduce assembly costs
2. Operating cost: increase indirect evaporative effectiveness by 10% and overall evaporative effectiveness by 5%

1.3. Report Organization

This report is organized as follows:

Section 1.0 Introduction

Section 2.0 Project Approach
Section 2.0 presents the approach and methodology.

Section 3.0 Project Outcomes
Section 3.0 explains the outcomes and results of the IDEC development and testing work.

Section 4.0 Conclusions and Recommendations
Section 4.0 outlines the conclusions drawn, benefits to California, recommendations for future steps and the commercialization potential for the IDEC unit.

There are five appendices.

- Appendix A: Gen 1 and Gen 2 Test Data
- Appendix B: Results of IDEC User Survey
- Appendix C: Diagram of Unit with Dimensions
- Appendix D: Approval of Test Results
- Appendix E: Detailed IDEC Test Plan

There is one attachment.

- Attachment 1: Advanced Evaporative Cooling White Paper

2.0 Project Approach

2.1. Counterflow Indirect Stage Heat Exchanger Design

2.1.1. Concept Description

Parallel plate indirect evaporative heat exchangers have alternating airflow passages. One set of passages encloses “dry” air that is cooled without adding moisture. Water distributed on the inner surfaces of the alternating “wet” passages evaporatively cools both the passing air and water in the passages. As air flows through these wet passages, the cooling effect causes heat transfer from the dry airstream to the fluids in the wet passages. Air in the dry passages is thereby cooled without moisture addition, and air leaving the wet passages, which is warm and humid, is rejected.

Indirect heat exchangers must be designed such that the dry and wet airstreams do not mix. The most straightforward way to prevent mixing is to use a “crossflow” pattern, in which the dry and wet airstreams travel perpendicularly to one another; and all four heat exchanger edges are used as airflow inlets and outlets. Virtually all prior indirect evaporative heat exchangers use crossflow design. However, counterflow heat exchangers, which use parallel airstreams in opposed flow, are typically more effective than those of crossflow design. This is because the average temperature difference between the two airstreams (the “wet bulb depression”), which is directly proportional to the heat transfer rate, is greater for counterflow than it is for crossflow. The IDEC unit developed in this project uses a novel, substantially counterflow design (see Figure 1).

In previous crossflow IDEC designs, wet passage airflow was vertical and dry passage airflow was horizontal. Using counterflow heat exchange enables both airstreams to travel mostly horizontally. Because the unit is designed to have a small footprint, the indirect stage is taller than it is wide. Therefore, for any given plate spacing, air moving horizontally sees a larger flow area than air traveling vertically. Consequently, for a given flow volume, wet passage air can move at lower velocity compared to prior vertical (cross)flow designs. This shorter path makes the counterflow design superior to crossflow for several reasons. First, it reduces the required wet passage width, thus allowing more dry passage flow area and volume. Second, the lower wet passage pressure drop reduces blower power for a given total flow volume. Third, the lower velocity wet passage air is cooled more because it spends more time in contact with wet passage walls.

The majority of air leaving the dry passages continues into the direct stage (see Figure 1). However, the entrance to the wet passages is also open to the exit of the dry passages, and therefore the pressure drop of the direct stage influences a portion of the dry air to reverse direction and enter the wet passages. Unlike prior IDEC designs with crossflow heat exchangers, air entering the wet passages is cooler than ambient outdoor air. The wet bulb temperature of air entering the wet passages is therefore lower, increasing evaporative effectiveness.

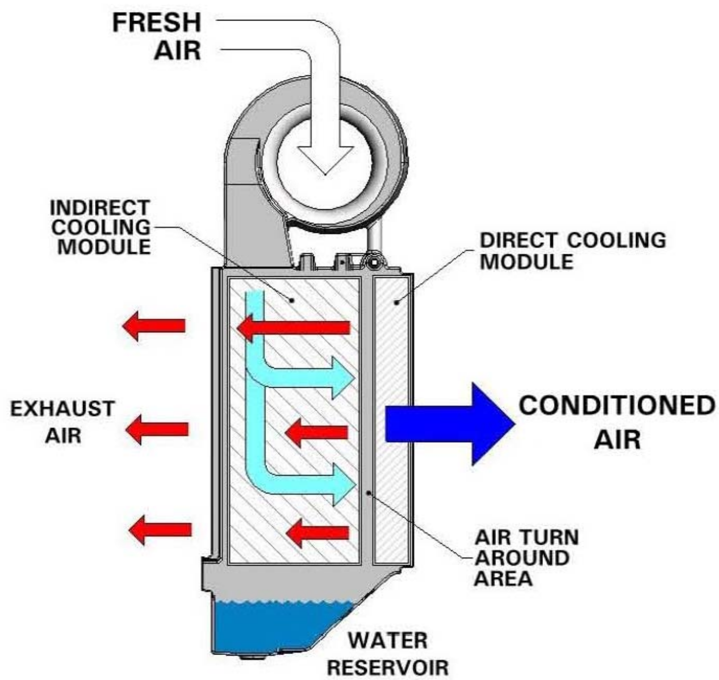

Figure 1. Schematic of IDEC Airflow Pattern

The indirect stage is designed so that air enters the dry passages traveling vertically and is then diverted to travel horizontally (Figure 1). This dry air pattern is not purely counterflow, but has several advantages. First, it allows the blower assembly to be mounted above the heat exchanger, minimizing the IDEC "footprint." Second, it allows dry air entry at a location that does not interfere with primary or secondary leaving air streams.

2.1.2. Prototype Evolution

The counterflow indirect heat exchanger design evolved through four iterations before the major decision to improve the cabinet and move the blower from below to above the heat exchanger. Design progression and results are described in detail in project monthly reports and task deliverables.

From December 1999 through May 2001, we evaluated a wide range of heat exchanger construction methods, and developed strategies for ensuring uniform water and air distribution in the plates. We developed and tested a series of mockup and full size heat exchangers, beginning with a concept for enclosing corrugated paper plates inside flattened plastic membrane tubes. A full-scale mockup of this first design was tested at Des Champs Laboratories in April 2000. We abandoned this concept after testing revealed unacceptably high pressure drops and noise.

After generating alternate concepts for non-corrugated designs, we contacted Jean-Jacques Chattot, an expert in computational fluid dynamics (CFD) at UC Davis, to assist with our sizing analyses. His modeling work helped to determine optimal plate spacing. We next pursued a concept of laminating flat treated paper (the same paper used in Munters Corporation's "CELdek" rigid evaporative media[1]) to thin plastic membranes. This approach proved valuable to successful project completion by enabling performance data to be generated without the cost of purchasing dies or molds for thermoformed plastic heat exchanger plates.

By assembling narrow modules of full-sized prototype plates fabricated of laminated paper and plastic membrane, we developed effective strategies for distributing air and water in our counterflow plate designs. We incorporated turning vanes into the dry passages to distribute the airflow evenly and to turn it to the horizontal direction and measured dry passage exit velocities to verify uniform air distribution. After a series of unsuccessful attempts, we ultimately developed a water distribution system that delivered water under pressure directly to the wet plate surfaces, where it wicked and flowed uniformly downward from the top edge.

By July 2001, we had designed the second indirect stage prototype, and established a working relationship with Munters Corporation and a plastic laminator to make our paper/plastic laminate. We experimented with alternate plate spacing strategies and selected thin strips of corrugated plastic signboard as the preferred spacers. We completed construction of a second full-scale prototype and delivered it to DCT in November, 2001. DCT tests in December showed good (45%) evaporative effectiveness, but the airflow rate was insufficient to match the cooling capacity of the base case CoolTech (Gen 2) unit. Therefore, we began design of a third prototype unit with improvements designed to increase airflow.

The third prototype, shipped to DCT in March 2001, showed a 23% increase in primary airflow compared to the second prototype; this unit also achieved higher indirect effectiveness (47%) than measured in any previous IDEC test. But primary airflow exiting the indirect stage remained 9% below that of the base case (Gen 1) unit. Based on this result, along with DCT's decision not to proceed with the project, we decided that the most intelligent adjustment we could make would be to widen the IDEC cabinet to 24", rather than to have performance constrained by the cabinet designed for the 20" wide AdobeAir heat exchanger. Committing to this change meant that we would need a wider heat exchanger that would fit within the wider cabinet, and this led to the development of an entirely new indirect heat exchanger, described in the next section and in detail in Section 3.1.

2.1.3. Thermoformed Plates

The high cost of existing residential two-stage evaporative coolers can be attributed in large part to the labor-intensive process of fabricating the indirect heat exchanger. This new IDEC design pioneers the use of "inline" thermoforming to inexpensively manufacture dry plate pairs with integral features such as spacers, air diverters, and snaps to hold the pairs together. In volume production quantities, the cost of manufacturing plates inline should be considerably less than any other heat exchange plate manufacturing process. Furthermore,

[1] CELdek is the most commonly-used rigid media in modern evaporative coolers.

the labor cost of assembling the plate pairs into an entire array should be greatly reduced as compared to other designs, especially those without built-in spacers and air diverters. There is additional promise for further automating the fabrication process by manufacturing an entire heat exchanger as one continuous sheet of plastic that is folded and then snapped together as it leaves the thermoforming machine.

2.2. Rotationally-Molded Cabinet Design

2.2.1. Concept Rationale

Gen 1 and Gen 2 IDEC cabinets were fabricated from more than a dozen sheet metal parts that were costly to fabricate and assemble and were subject to both corrosion and leakage. When DEG made the decision to design a new, wider cabinet for the Gen 3 unit, we concluded that a one-piece polymer cabinet with integral blower housing would alleviate many of the problems associated with sheet metal. Rotational molding, ideal for manufacturing large, complex parts in low to medium quantities, was the clear choice among manufacturing processes. Furthermore, because DEG had gained experience designing and working with rotational molds in a previous project, we were able to efficiently design the part. This design promises to be less expensive and significantly more durable than a comparable sheet metal cabinet.

2.2.2. Development Process

The Gen 1 and Gen 2 IDEC airflow configurations exhausted air through the top. To achieve a small footprint, the resulting design placed the blower motor below the indirect stage. Gen 2 units experienced water leaks into the motor circuitry that caused serious maintenance issues. Counterflow indirect stage design, with secondary exhaust through the back, allows the blower motor to be on top. The top blower location maintains the small footprint and eliminates the danger of water leaks from the sump to the motor. It also greatly simplifies mold design, because the sump and blower housing, which are the two most complicated features of the cabinet, are located in separate regions.

After completing the conceptual design of the cabinet, DEG created detailed drawings for the cabinet mold, and commissioned mold fabrication by the Wheeler Boyce Company of Ohio.

2.2.3. Water Distribution System

Where possible, we integrated water distribution features into the molded cabinet. For example, a cavity on the exterior of the sump is designed specifically for the pump and other auxiliary components. Also, piping that delivers water to the top of the unit runs between structural ribs in the cabinet, and recesses for the water distribution manifold are located on the interior of the top surface of the cabinet. We also placed the drain opening at the lowest point in the sump, to ensure that water that water will completely drain, thus reducing the risk of biological growth between operating cycles.

Standard practice recommended by the Munters Corporation is to distribute water to evaporative media through a perforated pipe with upward spray against a reflective “half-pipe” facing downward. This approach did not work well for either the indirect or the direct stage in our new cabinet. We therefore developed a proprietary water feed design that is significantly less prone to clogging, more serviceable, and distributes water uniformly to each of the indirect stage water troughs.

2.3. Testing

2.3.1. Test Rationale

Testing was necessary both to determine whether the new design meets the project goal of exceeding Gen 2 performance by at least 5%, and to generate performance parameters necessary to estimate statewide performance. We developed a detailed test plan as provided here in Appendix E. Performance data are also useful for marketing and to guide future design modifications. We completed testing at DEG facilities under the supervision of Michael Apte, Senior Scientist at the Lawrence Berkeley National Laboratory. See Appendix D for his letter of approval.

2.3.2. Test Apparatus

We mounted and instrumented the IDEC unit in a south-facing wall of the DEG shop in Davis. Sensors measured dry and wet bulb temperatures and humidities in plenums mounted to the inlet, exhaust and supply airstreams. Figure 2 shows a photo of the test setup, including the inlet plenum (above the unit) and the supply plenum (to the right in Figure 2). We attached flow nozzles and pressure sensing devices to the supply and exhaust plenums to measure airflow rates. We used a Blower Door (the fan device in Figure 2) and a DuctBlaster, both purchased from the Energy Conservatory[2], for flow nozzles in the supply and exhaust plenums, respectively. These devices are equipped with integral variable speed fans that we used to adjust the pressure drop across the supply and exhaust plenums.

[2] The Energy Conservatory home page is: www.energyconservatory.com

Figure 2. IDEC Test Apparatus

To simulate ductless conditions, we adjusted pressure in both plenums to "zero static." To simulate ducted conditions, we adjusted the exhaust plenum fan to zero static, but turned the Blower Door fan off, resulting in a pressure drop across the supply plenum of about 0.18" of water at high speed. We recorded energy consumed by the blower fan and the pump, as well as sump water temperature. Due to a water meter malfunction, we were only able to record total water consumed over the duration of testing.

The two Data Electronics DT50 dataloggers retrieved temperature, humidity, and power data on six second intervals, and averaged and stored this data in thirty second intervals. A laptop computer recorded pressure measurements across the flow nozzles, which were subsequently converted to flow rates, also on thirty second intervals. We checked sensor calibrations and made any necessary adjustments at the beginning of each test day.

To match test conditions used to characterize Gen 1 and Gen 2 performance, we needed inlet air with approximately 100°F dry bulb temperature and 30°F wet bulb depression. To achieve these temperatures in tests that extended into a cool but sunny October, we built a Southside "greenhouse" of clear plastic sheet that warmed IDEC intake air.

2.4. Statewide Performance Projections

The laboratory results provided performance data at specified test conditions. To estimate IDEC full season performance in typical California applications, we used the MICROPAS two-stage evaporative cooler simulation model from the original IDEC development project for the Energy Commissions' ETAP program. MICROPAS models were used to simulate cooling performance for both IDEC and conventional cooling systems and applied to two building types (one residential, one modular classroom) in eight California climate zones.

3.0 Project Outcomes

3.1. Counterflow Indirect Stage

3.1.1. Design

The indirect stage is built with thermoformed plastic sheets with features that provide structure and guide both water and air (Figure 3). These sheets are manufactured with a production-quality aluminum tool that was designed in-house and fabricated at a contract thermoformer, AVC Corporation in Torrance, CA. When folded, each sheet becomes a "plate pair" that surrounds the dry air passages. When placed side-by–side, the plate pairs define the wet passages.

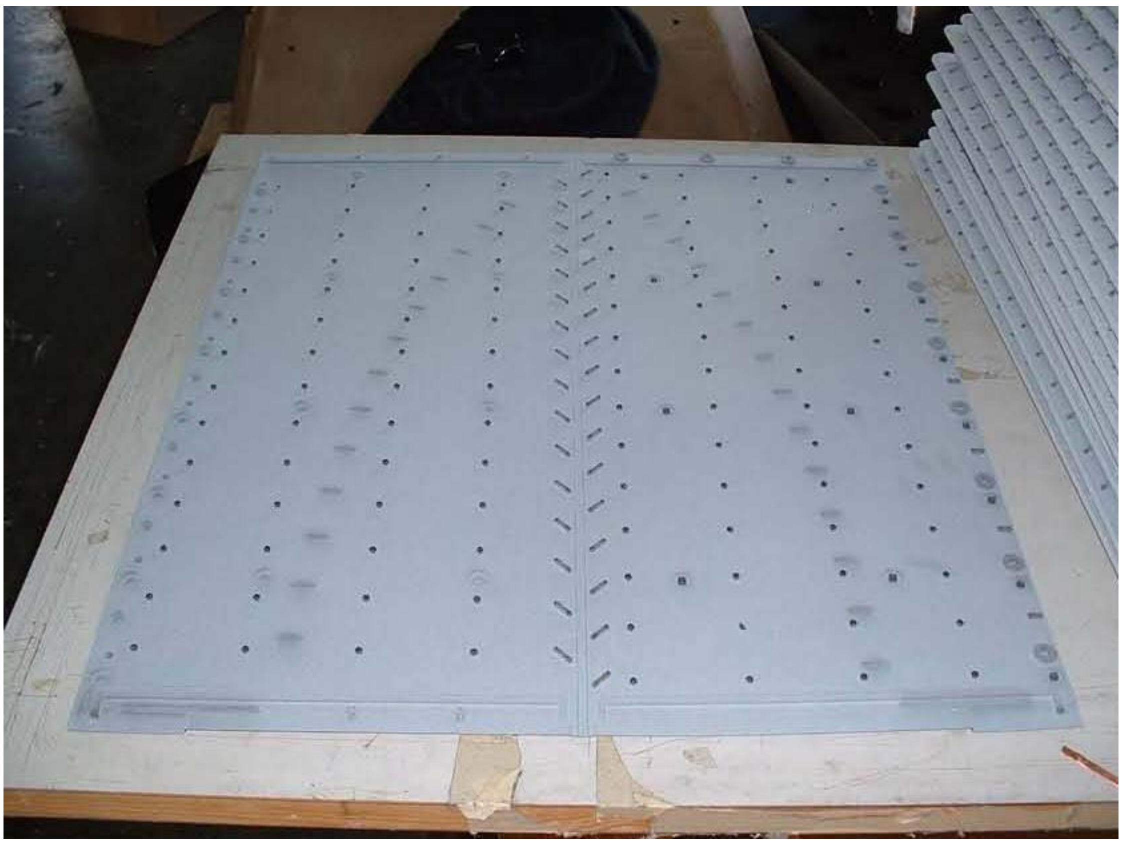

Figure 3. Unfolded Indirect Stage Plate, Flocked Side Facing Up

Both water and (outdoor) blower discharge air enter the heat exchanger along its top surface. To prevent mixing of water and incoming dry air, the water enters through a forward top area that is closed to dry airflow. However, for optimal plate wetting the water must distribute across the entire top edge of each wet plate. The plates are thus designed with integral water channels that are closed to the dry incoming air yet span the full plate length. These channels are formed by mating cavities in the thermoformed plates.

We sized the dry passage spacing based on our experience with the paper/laminate prototypes built earlier in the project. Since all inlet air passes through the dry passages before splitting into supply air (that enters the direct stage) and secondary air (that enters the wet passages), dry passage spacing is greater than for the Adobe heat exchangers used in the Gen 1 and Gen 2 units.

The built up heat exchanger is shown resting on its side in Figure 4. The grey and black surface at left is the unit's top, and the grey surface in the right of the picture is the back. Air enters the dry passages through the black portion of the top of the unit, and water is distributed over the grey region of the top. Exhaust air leaves the assembly from the back.

Figure 4. Top View of Indirect Stage

Figure 5 shows another photo of the built heat exchanger, as viewed from the front, which is the surface that faces the direct stage. Both the wet and dry passages are open to this face.

Figure 5. Front View of Indirect Stage

3.1.2. Test Results

Preliminary testing with plates formed on a prototype tool indicated that supply airflow would exceed our target of 1700 cfm. Therefore we increased wet passage spacing in the design of the production tool and reduced the total number of plates, to increase secondary flow and indirect stage effectiveness.

The original plate design used bare plastic plates and a separate "wicking strip" above each wet passage to distribute water along the top edges. When the initial tests showed that water did not distribute evenly across the plate surfaces, we reconfigured the design to use plates surfaced with wettable synthetic flocking (the grey surfaces visible in Figures 3-5). We were also able to redesign the plate thermoforming tool so that the flocked surfaces alone, without the wicking material, formed the upper water distribution channel.

Although flocking increases plate cost, eliminating the wicking strips reduces material costs and both assembly and maintenance labor.

3.2. Rotationally-Molded Cabinet

3.2.1. Design

Figure 6 shows the rotational cabinet mold in closed position, and Figure 7 shows an untrimmed cabinet produced from the mold and lying on one side. Notable features in Figure 7 include the top-mounted blower housing (to the right), structural ribbing (on the top surface as viewed), an integral sump located in the bottom region of the cabinet (to the left in the figure) and cavities for housing lower electrical components such as the pump and fill valve. Appendix C depicts detailed drawings of an assembled unit with overall dimensions. Before components are installed in the cabinet, it must be trimmed to provide air intake and exhaust routes.

Figure 6. IDEC Rotational Mold

Figure 7. Untrimmed Cabinet

3.2.2. Test Installation

The test unit cabinet is shown in Figure 8. It is watertight, water drains from it completely when the drain valve is opened, and the blower housing functions well. Additional enclosure features needed for a complete IDEC installation vary by application. Figure 8 shows an assembled IDEC unit ready for installation in an interior closet. For exterior installations, a screened housing is required atop the unit to prevent the entry of water and debris.

Figure 8. Fully Assembled Test Unit

3.3. Testing

3.3.1. Results

Table 1 shows lab test results for the Gen 3 unit. Since several minutes are required to reach steady state performance after any significant change in conditions, in the analyses we did not include data from the first ten minutes of each run. The values reported above are the average performance of the system for the remainder of each test period; the steady-state duration was at least 20 minutes in each case. From the data, we computed total effectiveness, capacity, and EER. We also computed "between-stage" dry bulb temperature, using the psychrometric chart, to disaggregate indirect and direct effectiveness.

Table 1. Results of IDEC Testing

Simulated Installation>>	Ductless			Ducted	
	High Speed	Medium Speed	Low Speed	High Speed	Low Speed
Fan Power, Watts	498	266	58	445	110
Total Power, Watts	521	289	81	468	133
Supply cfm	1551	1251	750	1250	750
Secondary cfm	622	478	250	800	490
Entering Air Dry Bulb, °F	104.7	103.7	104.3	103.1	106.5
Entering Air Wet Bulb, °F	70.8	71.1	73.0	73.3	74.3
Between stage Dry Bulb, °F	87.0	85.0	84.5	80.5	82.9
Leaving Air Dry Bulb, °F	67.8	67.8	68.8	68.7	69.1
Leaving Air Wet Bulb, °F	65.0	65.3	67.2	66.6	67.5
Indirect Effectiveness, %	52.2	57.2	63.3	75.7	73.3
Direct Effectiveness, %	87.1	87.4	91.0	84.8	89.6
Total Effectiveness, %	108.9	110.1	113.6	115.3	116.2
Capacity, Btu/hr	20,660	17,155	11,128	19,257	11,770
Capacity, tons	1.72	1.43	0.93	1.60	0.98
EER	40	59	136	41	88

Five operating conditions are shown in Table 1: ductless high, medium, and low speeds, and ducted high and low speed. We found that the ¾ hp GE electronically commutated motor (ECM) supplies a maximum of approximately 1350 cfm in ducted conditions, and therefore 1250 cfm was defined as the high speed operating condition in the ducted case.

Total effectiveness, defined as the ratio of the difference between outdoor and supply air temperatures and the difference between outdoor dry bulb and wet bulb temperatures, is higher for the Gen 3 unit than for any of its predecessors. Specifically, the Gen 3 unit is between 2 and 10% more effective than the Gen 1 and Gen 2 units (see results in Appendix A). This improvement is attributable to the counterflow indirect stage, which reached effectiveness values greater than 70% in ducted conditions. The end result is that, compared to its predecessors, the Gen 3 unit can deliver cooler air. Therefore it can achieve a desired room temperature with a lower airflow rate, will add less moisture to the space, and consume less fan energy compared to prior units. The resulting energy savings are further enhanced by the fact that effectiveness increases with decreasing airflow rates, allowing the unit to operate at an even lower flow rate than if effectiveness remained constant.

Capacity is a measure of the amount of cooling energy delivered and, though imperfect, it is the best way to compare two-stage evaporative cooler performance to vapor compression systems. It is computed using the following formula:

Equation 1

$$q_s = \dot{Q} \times \rho \times c_p \times (TAR_{DB} - TAO_{DB} + EFF_{tot} \times (TAO_{DB} - TAO_{WB})),$$

where q_s is the system capacity, $\dot{Q}$ is the airflow rate, ρ is air density, c_p is the specific heat of air, EFF_{tot} is the system effectiveness, and TAR_{DB}, TAO_{DB}, and TAO_{WB} are the indoor dry bulb temperature, outdoor dry bulb temperature, and outdoor wet bulb temperature, respectively. To calculate the results in Table 1 we used Sacramento design conditions: 101°F DB/70°F WB, and an indoor temperature of 80°F.

Equation 1 provides a conservative estimate of two-stage cooler capacity as compared to vapor compression systems, because two-stage coolers:

1. Eliminate infiltration by pressurizing the conditioned space
2. Eliminate unnecessary latent cooling; and
3. If building exhaust air is vented through an attic, reduce ceiling heat gains[3].

EER, or energy efficiency ratio, is the ratio of the system capacity (in Btu per hour) to energy consumption (in Watt-hours, or Wh). Vapor compression cooling systems of comparable capacity typically have EER values of approximately 10. As Table 1 shows, IDEC unit EER values are significantly more efficient than any vapor compression system they might replace. The difference in energy consumption is even more impressive if one considers that vapor compression rated EER does not include energy consumed by the indoor section's supply air blower; it only accounts for energy use of the condensing unit.

In simulated ducted operation, the supply air was pressurized, increasing the secondary (wet passage) airflow rate. This tendency increased effectiveness, due to the higher secondary air percentage, and capacity, due to higher effectiveness. In fact, ducted capacity at 1250 cfm was found comparable to unducted capacity at 1550 cfm. However, EER at a given capacity is lower in the ducted configuration, due to its higher blower power resulting from increased secondary airflow.

The maximum airflow rates measured for the unit were approximately 1650 cfm for unducted simulations and 1350 cfm with a pressure drop of 0.18" of water. These flow rates could be increased with greater blower power. The ¾ hp GE motor consumed approximately 560 Watts at full speed—less than expected for its rating. It may be possible to reprogram the motor to deliver more cfm. For applications requiring additional air volume, a 1 hp motor could also be substituted, as the two motors are exactly the same size.

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[3] Steven Winter Associates is studying this very phenomenon. See the Coalition for Advanced Residential Buildings (CARB) website, http://www.carb-swa.com/, for more information.

3.3.2. Water use

We monitored water consumption during steady state operation and found that IDEC uses an average of 4.3 gallons per hour at 750 cfm, 5.6 gallons per hour at 1250 cfm, and 7.4 gallons per hour at 1550 cfm. These rates do not reflect water consumption that would result from programmed sump flushes (which control mineral concentration in the sump water) or water required to fill the sump at the beginning of a run cycle. Taking these into account, water usage rates on a typical day when the unit operates for 5 hours should vary from a minimum of approximately 6 gallons per hour at 750 cfm to a maximum of 11 gallons per hour at 1550 cfm.

3.3.3. Discussion

We have used results from 1998 PG&E Gen 2 laboratory testing (shown in Figure 9 and Figure 10 and detailed in Appendix A) for baseline data to determine if we have met the goal of exceeding Gen 2 indirect stage performance by at least 5%. Using a 1 hp motor, the Gen 2 unit achieved higher airflow than the ¾ hp Gen 3, but the data shown in Figure 9 and Figure 10 clearly indicate that the performance goal (5% improvement over Gen 2) has been met on measures of effectiveness and EER.

The highest indirect stage effectiveness measured during unducted testing at PG&E was 29% at 1290 cfm. In comparison, the Gen 3 indirect stage effectiveness was calculated to be 57% at 1250 cfm in unducted conditions; this represents a 96% increase over Gen 2 performance. Gen 1 indirect effectiveness equaled Gen 3's at 1250 cfm, but Gen 3 shows an average improvement of 4% over the Gen 1 unit when all three tested flow rates are considered. Overall effectiveness values calculated from the tabulated data plotted in Figure 9 show Gen 3 averaging 9.5% higher than Gen 2 and 2.5% higher than Gen 1.

Figure 10 shows that Gen 3 EER significantly exceeded those for both prior generations. Due to a combination of higher effectiveness and lower power consumption, Gen 3 EER averaged 90% higher than Gen 2 and 32% higher than Gen 1 across a comparable flow range. These results demonstrate that the counterflow indirect stage improves IDEC effectiveness and significantly improves IDEC EER. We attribute the substantial gains in EER to the counterflow heat exchanger's wider primary airflow passages and pre-cooled secondary (wet passage) inlet air.

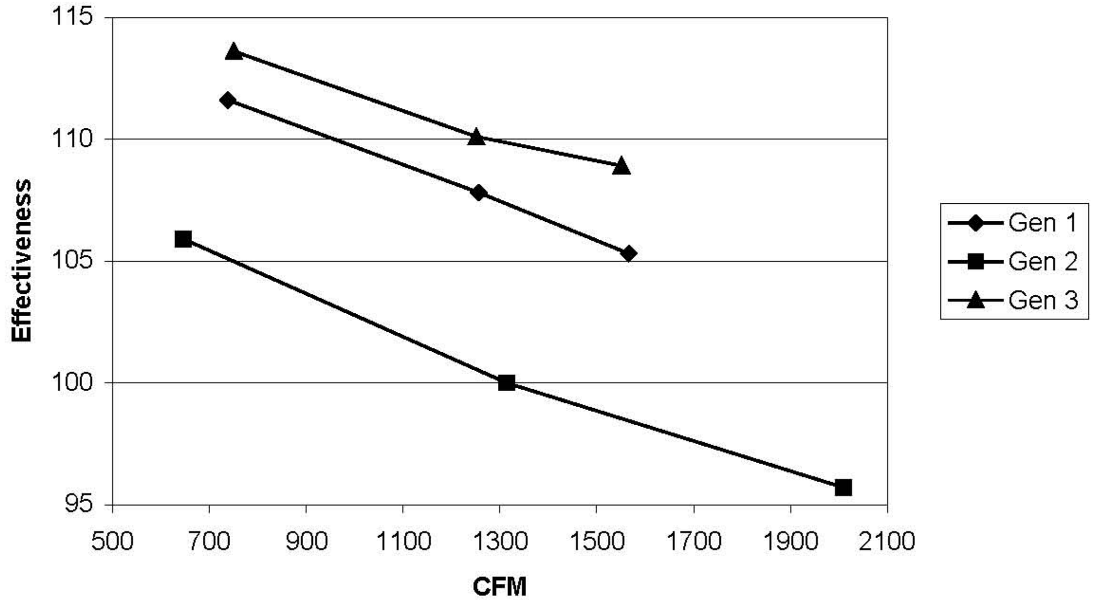

Figure 9. Effectiveness versus Airflow Rate in Unducted Conditions, for all Three IDEC Generations

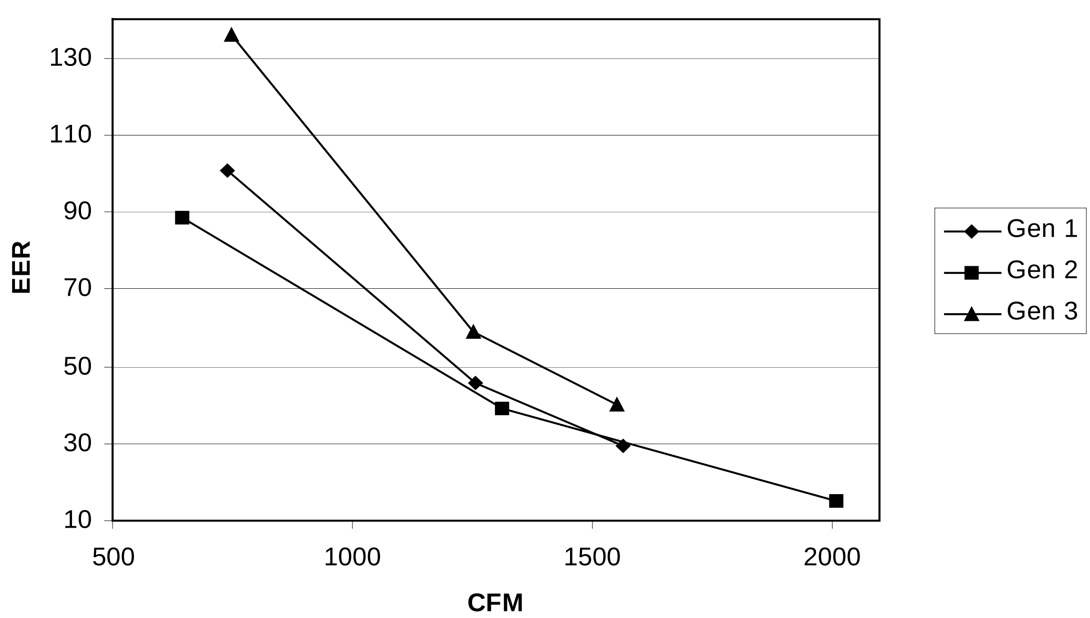

Figure 10. EER versus Airflow Rate in Unducted Conditions, for all Three IDEC Generations

Once the decision was made to proceed with thermoformed plates, little time and budget were left for evolutionary development. Therefore, although Gen 3 performance is significantly better than any of its predecessors, we believe that EER and effectiveness can be even further improved with fine-tuning of plate spacing and other details in future heat exchanger generations.

3.4. Statewide Performance Projections

3.4.1. Results

For full year simulations, we selected eight of the sixteen California climate zones[4] with moderate to high summer design temperatures, and with significant residential construction potential over the next decade. Table 2 shows these selected zones and the corresponding summer design temperatures.

Table 2. Climate Zone Summary

Climate Zone	Location	Summer Design Dry Bulb (0.5%)	Climate Characterization	Evaporative Cooling Load
2	Santa Rosa	96°F	N. CA; coastal/transitional	7,465 kBtu/yr
6	Long Beach	90°F	LA area; coastal	4,729
8	El Toro	89°F	LA area; transitional	4,757
9	Burbank	96°F	LA area; inland	6,960
10	Riverside	102°F	LA area; inland	10,822
12	Sacramento	100°F	Central Valley; hot/inland	9,055
13	Fresno	101°F	Central Valley; hot/inland	16,356
15	El Centro	111°F	S. CA; inland/very hot; low desert	39,831

Table 3 summarizes projected performance for IDEC and a 10 Seasonal Energy Efficiency Ration (or SEER—see glossary) base case cooling system in a typical 1600 square foot house. The projections are based on continuous thermostat setpoints[5]. Projected annual cooling savings average 93% over the 8 climate zones, and demand savings average 84%.

The simulations predict adequate capacity for the sample buildings in all but Climate Zone 15, where the projected indoor temperature will exceed 80°F for 100 hours per year. A second IDEC unit or a backup air conditioner would be needed to insure comfort in Climate Zone 15 on the hottest days[6].

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[4] For a map of California's climate zones, see http://www.energy.ca.gov/maps/climate_zone_map.html

[5] "Full-day" climate control is beneficial for IDEC units, by allowing gradual speed ramping as loads vary, minimizing blower speed and energy use. Occupants who leave their cooling system off when their home is unoccupied may not realize the energy savings shown in Table 3.

[6] Conventional air conditioning paired with evaporative cooling is common in hot desert climates.

Table 3. Performance Projections for the 1,600 ft^2 House

Climate Zone	Base Case Cooling kWh/year	Base Case Cooling Peak kW	IDEC Cooling kWh/year	IDEC Cooling Peak kW	Savings kWh	Savings kW
2	933	3.4	61	0.52	93%	85%
6	418	2.5	31	0.52	93%	79%
8	478	2.8	39	0.52	92%	81%
9	765	2.6	58	0.52	92%	80%
10	1389	3.7	75	0.52	95%	86%
12	1178	3.5	72	0.52	94%	85%
13	2357	3.7	135	0.52	94%	86%
15	6858	4.8	515	0.52	92%	89%

Modular classrooms (also referred to as relocatable classrooms), which are being built in large numbers in California and elsewhere in the United States, are especially well suited to IDEC installation for several reasons. First, they require high indoor environmental quality (IEQ), which IDEC units easily deliver by supplying 100% outdoor air. Second, they are self-contained structures with dedicated HVAC systems that are ideally sized for IDEC capacity. Modular classroom performance projections are shown in Table 4. This scenario provides large blower savings because the IDEC unit can provide minimum ventilation airflow rates when cooling is not required, while the base case unit must operate at constant speed to deliver required ventilation air whether cooling is needed or not. The IDEC is undersized for Climate Zone 15 in the modular classroom application, with predicted indoor temperature exceeding the setpoint for 140 hours each summer. Although not shown in Table 4, projected IDEC demand reductions in modular classrooms ranged from 81% to 91%.

Table 4. Modular Classroom Energy Performance Projections

Climate Zone	Base Case Energy Use (kWh/yr) Compressor	Base Case Energy Use (kWh/yr) Total	IDEC Energy Use (kWh/yr) Cooling	IDEC Energy Use (kWh/yr) Total[7]	Annual Savings (%)
2	1213	2244	133	225	90%
6	1194	2225	128	220	90%
8	1196	2227	150	242	89%
9	1359	2390	148	240	90%
10	1729	2760	160	252	91%
12	1357	2388	150	242	90%
13	1909	2940	205	297	90%
15	4465	5496	500	592	89%

[7] This includes energy consumed by the unit while providing ventilation air only (the water pump is off in this case)

These results indicate that on a seasonal basis the IDEC units will operate at efficiencies 9 to 18 times higher than conventional systems; operated at the assumed conditions, the IDEC seasonal energy efficiency ratios (SEERs) were found to range from 92 to 185 compared to the standard 10 SEER air conditioner. One expected result of this substantially higher efficiency, as borne out by a comparison of 1994 and 1995 Gen 1 IDEC field test data[8], is that users will lower thermostat settings when they are aware of IDEC cooling efficiencies. This "take-back" effect will probably reduce savings below the levels shown here, but should also result in enhanced cooling comfort compared to the 80°F base case indoor condition.

3.5. IDEC Market Opportunities

Based on excellent lab testing results and performance simulations, improved manufacturability and significantly reduced costs (see below), the Gen 3 IDEC unit has incredible market potential. Thanks to IDEC's high effectiveness, its geographic range will be greater than any of its predecessors and it should compete much more favorably with traditional vapor compression systems. We expect that the Gen 3 IDEC's energy efficiency will attract the attention of many California utilities, and that it should be especially attractive in cases where continuous ventilation air is required, as in modular classrooms and other school applications.

3.5.1. Manufacturing Agreement

DEG and the Speakman Company have signed a "letter of intent" as a precursor to a manufacturing license agreement. At the time of this report, DEG has provided the Speakman Company with a working prototype, and Speakman has accepted the prototype results. We expect the letter of intent to lead to a licensing agreement early in 2004. Speakman has indicated an interest in testing IDEC units in the field as soon as possible.

3.5.2. Market Plans

The Speakman Company has been diligently researching IDEC market potential and considers advanced evaporative cooling technology to be a natural growth industry. They are working with representatives from key target markets, including military housing, modular classrooms, and post offices.

3.6. Cost Reduction

Table 5 is a cost breakdown table comparing cabinet and indirect stage materials and labor costs for the Gen 2 and Gen 3 units in 500 unit quantities. As the table shows, Gen 3 components are significantly less expensive for Gen 3. The total cost reduction of $386 should lead to at least an $800 reduction in installed cost.

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[8] See "Indirect/Direct Evaporative Cooler Monitoring Report**," Davis Energy Group for Pacific Gas & Electric Company, 1995, and "**Indirect-Direct Evaporative Cooler (IDEC) Development Project Final Report**," P500-90-024, Davis Energy Group for California Energy Commission, 1995.**

Table 5. Cost Comparison

Gen 2 vs. Gen 3 Cost Comparison, in 100 Unit Quantities		
	Gen 2*	**Gen 3**
Cabinet costs		
Blower housing	$60.76	
Control housing	$13.07	
Shroud	$41.30	
Cabinet	$154.70	
Accessories	$9.38	
Paint	$56.50	
Rotomolded cabinet		$97.75
Top shroud		$20.00
Assembly/trim	$30.00	$20.00
Heat Exchanger costs		
AdobeAir indirect stage	$282.50	
Total Gen 3 plate cost		$94.00
Gen 3 assembly costs		$30.00
Total cabinet and heat exchanger costs	**$648.21**	**$261.75**
Gen 3 cost reduction		**$386.46**

*Gen 2 costs were last calculated in 1998, here they are converted to 2003 dollars

4.0 Conclusions and Recommendations

4.1. Technical Objectives

This project has led to an all-new and radically improved IDEC unit that exceeds the original project objectives, most notably on the basis of design flexibility, quality, and efficiency (see Section 1.2.2, Final Project Objectives), as explained in the following sections.

4.1.1. Design Flexibility

The original project anticipated development of an improved, custom-produced crossflow heat exchanger that could be assembled in various widths for a range of IDEC sizes. At project completion we had developed and tested a new counterflow heat exchanger with superior performance. The innovative heat exchanger is tailored for the vertical unit, and uses a variable number of plate pairs that can be assembled quickly to any desired width.

4.1.2. Quality

Goals in this category were to eliminate adhesives in heat exchanger assembly, and to improve leakage protection and corrosion resistance in the cabinet. We accomplished the heat exchanger assembly goal by developing a thermoformed plastic plate system with integral spacers and snaps that facilitate rapid folding and holding of plate pairs, and other spacers and edge features that facilitate assembly of multiple plate pairs into heat exchanger blocks using crimping strips at mating edges of the plate pairs. We accomplished the cabinet improvement goals by developing a one-piece, corrosion-proof polymeric unit that integrates the heat exchanger and blower housings, the water reservoir, and recesses for pumps and other operating components. We also moved the blower to the top of the unit, above all "wet" components, to better protect the valuable blower motor.

4.1.3. Higher Efficiency

The quantitative goal in this category was to improve indirect evaporative efficiency by 10% and overall efficiency by 5% compared to the Generation 2 IDEC unit. Test results show that the Gen 3 indirect stage achieves 97% higher effectiveness than the Gen 2. Gen 3 also exceeded Gen 1 indirect effectiveness by 4%. Gen 3 exceeded Gen 2 in overall evaporative effectiveness by 9.5% and exceeded Gen 1 overall effectiveness by 2 to 4%. Overall efficiency gains were even more remarkable, due in part to Gen 3's lower power consumption compared to the prior units. Across a comparable speed range, Gen 3 EERs averaged an impressive 90% higher vs. Gen 2 and 32% higher vs. Gen 1.

4.2. Economic Objectives

This project has substantially exceeded the project economic goals by developing an improved IDEC unit with lower initial and operating costs than the prior units, as follows:

4.2.1. Initial Cost

The project goal was to reduce product cost by $300. Our estimates (see Table 5) indicate that the Gen 3 unit can be produced for $386 less compared to the Gen 2 unit. This amount should ultimately, when high volumes are achieved, translate to a $600 to $800 reduction in price to the purchaser. This large initial cost reduction will substantially enhance IDEC marketability.

4.2.2. Operating Cost

The project goal was to increase efficiency by 5% compared to the Gen 2 unit, which translates to a targeted 5% reduction in operating costs. Comparative EERs are the best measure of expected operating cost savings compared to prior IDEC generations. The Gen 3 unit substantially exceeds this goal; its 90% higher projected EER compared to the Gen 2 unit translates to 47% operating cost reduction. The Gen 3 unit should even reduce operating costs by 24% compared to the Gen 1 unit.

4.3. Benefits to California

4.3.1. Peak Load and Pollution Reduction

Our test results and simulation results indicate that even at modest market penetration levels, the Gen 3 IDEC unit can significantly reduce statewide peak demand. The data in Table 3 of section 3.4 indicate that replacing a 10 SEER condensing unit with a Gen 3 IDEC in a typical home will reduce peak demand by roughly 2.8 kW. It follows that the installation of 10,000 units into the California retrofit market could reduce statewide peak demand by approximately 28 MW.

Peaker power plants, which are typically the most expensive to operate, are often old and inefficient. Consequently, pollutant emissions from these sources are disproportionately high. Once adopted in the marketplace in significant numbers, IDEC technology will diminish, and in some cases eliminate, the need to run the dirtiest peaker plants. IDEC's overall impact on air quality will therefore be large in comparison to other technologies that offer the same total energy savings but have lower on-peak impact.

4.3.2. Energy Efficiency & Associated Benefits

The potential for the Gen 3 IDEC to reduce total energy consumption is equally impressive. The data in Table 3 of section 3.4 show that replacing a 10 EER condensing unit with a Gen 3 IDEC in a typical home will save approximately 1500 kWh per year (averaged across the California climate zones we considered). Thus, operating 10,000 IDEC units in place of conventional cooling units would save roughly 15 GWh per year, and would contribute significantly to California's commitment to reduce greenhouse gas emissions.

4.3.3. Indoor Air Quality in Schools

Scientists headed by Michael Apte at Lawrence Berkeley National Laboratory have completed extensive studies on Gen 2 IDEC performance in modular classrooms1. Their findings indicate that, in addition to providing significant energy savings, IDEC units improve indoor air quality by providing 100% outdoor air and running continuously at low speeds. Contaminants such as volatile organic compounds and particulate matter, which significantly affect occupant health, are therefore reduced in buildings that use IDEC units. Gen 3 designs maintain the Gen 2 features that provide these indoor air quality advantages.

4.4. Recommendations and Commercialization Potential

While Gen 3 IDEC development and testing work indicate that the unit has substantial potential to reduce statewide energy consumption, additional R&D steps are needed for the new IDEC unit to achieve its market potential. The following "next steps" are recommended for ongoing PIER Program support:

4.4.1. Additional Component Development

a. *Accessory enclosures*- In its current form, the IDEC includes a basic cabinet, without needed enclosure components that will vary with field mounting configuration. For exterior wall mounting, expected for modular classroom and some residential retrofit applications, a support bracket set to reduce installation time and an upper housing that screens or filters intake air and provides weather protection for the motor and controls will be required. For flush or interior applications, a screened inlet louver set with integral mounting brackets would reduce installation time. These components will reduce installation first costs and should increase HVAC contractor enthusiasm for the IDEC unit.

b. *Internal drain valve*- The current motorized drain valve is expensive and projects downward from the bottom of the unit. The IDEC sump has been designed to accommodate a proprietary internal, non-motorized drain valve. This spring-loaded device will use water as the driver; water added at start up and maintained during operation closes the valve, which drains after shutdown and then springs open to drain the sump. The expected difference in cost for volume production is $5 vs. $40 for the current valve, and the auto-drain valve would not show or require vertical clearance below the IDEC.

c. *Optimized indirect plates*- The current design is a first for inline thermoformed plates. Additional iterations with alternate plate thickness, spacing, and turbulence features are likely to further improve indirect effectiveness and help identify an optimal design. Each 1°F reduction in indirect stage dry air outlet temperature results in approximately 8% performance improvement, so optimization will be valuable in further extending IDEC market range.

d. *Upgraded controls*- The Gen 3 unit currently uses the electronic control board and thermostat developed for the Gen 2 unit in 1997. Recent advances in printed circuit board technology should be applied to develop a smaller, more reliable, and less expensive control board.

e. *Vapor-compression booster stage*- IDEC's indirect cooling stage substantially expands its market range compared to direct evaporative coolers, but applicability remains limited to relatively dry climates. We designed the new IDEC cabinet to accommodate a vapor-compression booster stage with evaporator coil at the supply air outlet and condenser coil at the exhaust air outlet. At peak conditions the boost would increase capacity by more than a ton and contribute to an overall EER of 24. The boost would only operate when needed, and would expand IDEC market reach well beyond the dry Southwest.

f. *Heating accessories*- With a damper set, a secondary exhaust shutter, and a heating coil/pump set for connection to the water heater, the IDEC could become a complete forced air heating and cooling system. This accessory could substantially enhance IDEC marketability for new buildings and modular classrooms.

4.4.2. Field Test and Demonstration Project

Operational and durability tests in the field are needed in a range of applications to verify IDEC promise and identify any control or component "bugs" that could discourage wide use of production units. A two-unit field test of PV-integrated IDEC units will be underway with SMUD support by Spring, 2004. At least four additional early field sites are recommended, with at least two of those in modular classroom settings. These field units should be monitored in detail. Soon after the field tests and correction of any operating problems, a demonstration project of twenty units or more, with monitoring of reliability and user response, would be valuable to further verify IDEC market readiness. This demonstration would begin to convince consumers and contractors that IDEC is energy efficient, reliable, easy to operate, and provides full comfort.

4.4.3. Further Plate Cost Reduction

The current design requires manual assembly of indirect heat exchanger plates. After working with an inline thermoformer to develop this high speed plate production process, we now see a way for complete heat exchanger assemblies to be automatically produced on a modified inline machine. This process would have widespread applicability for air-to-air heat exchangers as well as IDEC and several other indirect evaporative applications conceived at DEG. We would like to work with a selected inline thermoformer to develop this process, which could generate another 20% cost reduction for the IDEC heat exchanger. We have also developed a lower cost concept than "flocking" to insure plate wetting. This process might also reduce indirect heat exchanger cost by 20%.

4.4.4. Develop "room size" IDEC

There is a huge potential market for a smaller IDEC that competes with window or "through-the-wall" air conditioners. These small AC units are widely used in mobile homes and older homes not equipped with central ducted systems. A small IDEC with less-expensive blower motor could be cost-competitive with current window/wall AC units, but deliver six-fold higher energy efficiency. Mounted near the ceiling, the small IDEC could include the relief air "upduct" into the attic or wall relief to the outdoors. These units could also be strategically located in high load areas of homes or other buildings already equipped with central AC.

We appreciate the opportunity to suggest these opportunities for future improvements to the IDEC technology developed in this project.

5.0 References

SMUD Indirect/Direct Evaporative Cooler Monitoring Report, *Davis Energy Group for Sacramento Municipal Utility District, 1993*

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Advanced Evaporative Cooling White Paper, *Davis Energy Group for Heschong Mahone Group and the California Energy Commission, 2002*

6.0 Glossary*

BLOWER	An air moving device
CABINET	Exterior covering and structural support for components of an evaporative cooler
CAPACITY	The amount of heat energy a device can add or remove in a certain amount of time. Evaporative cooler capacity only measures sensible cooling capacity.
COUNTERFLOW	A heat exchange flow pattern in which fluids travel in parallel and opposite directions
CROSSFLOW	a heat exchanger flow pattern in which fluids travel perpendicular to one another
DEG	Davis Energy Group, Inc.
DIRECT EVAPORATIVE COOLER	A device that evaporatively cools air by adding moisture
DIRECT STAGE	The direct evaporative cooling section of a two-stage evaporative cooler
DRY BULB TEMPERATURE	A measure of the sensible temperature of air
ECM	Electronically Commutated Motor. The speed of these motors is continuously adjustable. They deliver air at the minimum rate to satisfy a cooling or heating load, which minimizes motor energy use.
EER	(Energy Efficiency Ratio) the ratio of cooling capacity of an air conditioning unit in Btus per hour to the total electrical input in watts under specified test conditions.
EFFECTIVENESS	The ratio of the difference between outdoor and supply air temperatures and the difference between outdoor dry bulb and wet bulb temperatures
EVAPORATIVE COOLER	A device that causes water to evaporate in air and thereby cool the air.
HEAT EXCHANGER	A device that transfers heat from one medium to another
INDIRECT-DIRECT AIR CONDITIONER (IDAC)	One of the commercial names used for the Gen 2 units in this report.

INDIRECT-DIRECT EVAPORATIVE COOLER (IDEC)	A device that cools one airstream without moisture addition via heat exchange with a second airstream that is evaporatively cooled. Also another name for the Gen 1 and Gen 3 units in this report.
INDIRECT STAGE	The indirect evaporative cooling section of a two-stage evaporative cooler
PIER	Public Interest Energy Research program, sponsored by the California Energy Commission
ROTATIONAL MOLDING (a.k.a. ROTOMOLDING)	A polymer molding process that is ideal for creating large, complex parts.
SEER (Seasonal Energy Efficiency Ratio)	the total cooling output of an air conditioning unit in Btus during its normal usage period for cooling divided by the total electrical energy input in watt-hours during the same period, as determined using specified federal test procedures. Applicable to vapor compression air conditioning systems only.
THERMOFORMING	The process of transferring a shape to a polymer material by heating the polymer so that it takes the shape of a mold. Typically the definition is restricted to the forming of thin plastic sheets
TWO-STAGE EVAPORATIVE COOLER	A device that combines an indirect evaporative cooling stage and a direct evaporative cooling stage in series.
WET-BULB DEPRESSION	The difference between the dry bulb and wet bulb temperatures
WET-BULB TEMPERATURE	The temperature to which water, by evaporating into air, can bring the air to saturation at the same temperature. Wet-bulb temperature is measured by a wet-bulb psychrometer.

*Many of these definitions were adapted from the California Energy Commission's Consumer Energy Center website, www.consumerenergycenter.org.

Appendix A: Gen 1 and Gen 2 Test Data

Table A-1: Results of 1994 Gen 1 testing at Adobe Air, unducted conditions

Simulated Installation>>	*Ductless*				
	High Speed	High Speed	High Speed	Medium Speed	Low Speed
Fan Power, Watts	610	609	620	325	74
Total Power, Watts	<-----------------------------------not reported----------------------------------->				
Supply cfm	1579	1533	1566	1256	738
Secondary cfm	485	507	493	405	236
Entering Air Dry Bulb, °F	102.6	92.3	102.5	98.2	100.4
Entering Air Wet Bulb, °F	73.0	69.9	72.3	71.4	72.9
Between stage Dry Bulb,°F	<-----------------------------------not reported----------------------------------->				
Leaving Air Dry Bulb, °F	71.5	68.8	70.7	69.3	69.7
Leaving Air Wet Bulb, °F	68.8	66.3	67.2	66.8	68.1
Indirect Effectiveness, %	49.0%	50.4%	55.3%	57.5%	57.5%
Direct Effectiveness, %	86.0%	83.0%	81.2%	84.4%	90.3%
Total Effectiveness, %	105.1%	104.9%	105.3%	107.8%	111.6%
Capacity, Btu/hr*	19074	18441	19034	16298	10484
Capacity, tons*	1.59	1.54	1.59	1.36	0.87
EER	30	29	29	46	101

Table A-2: Best values reported for 1998 Gen 2 PG&E testing, unducted conditions

Simulated Installation>>	***Ductless***		
	High Speed	**Medium Speed**	**Low Speed**
Fan Power, Watts	<-----------not reported----------->		
Total Power, Watts	1186	349	90
Supply cfm	2009	1314	646
Secondary cfm	<-----------not reported----------->		
Entering Air Dry Bulb, °F	108	109	83
Entering Air Wet Bulb, °F	85	89	66
Between stage Dry Bulb,°F	<-----------not reported----------->		
Leaving Air Dry Bulb, °F	86	89	65
Leaving Air Wet Bulb, °F	84	88	65
Indirect Effectiveness, %	<-----------not reported----------->		
Direct Effectiveness, %	<-----------not reported----------->		
Total Effectiveness, %	95.7	100.0	105.9
Capacity, Btu/hr*	18147	13718	7974
Capacity, tons*	1.51	1.14	0.66
EER	15	39	89

*Capacity is calculated as described in Section 3.3.1, using 101°F DB/70°F WB outdoor conditions and 80°F indoor conditions.

Appendix B: Results of IDEC User Survey

IDEC/IDAC Customer Satisfaction Analysis Summary Report

Background: This report summarizes work we completed in May 2002 to assess customer satisfaction levels among users of two Indirect/Direct Evaporative Cooler designs, IDEC and IDAC.

Six IDEC prototype units were produced by AdobeAir participating as the manufacturing partner in the Energy Commission/ETAP 1995 IDEC Development Project led by DEG. We monitored field performance of the six units extensively under the development project. This design featured small footprint, single pump and sump, single variable speed blower with proportional speed control upstream from the media, automatic sump purge, and was awarded U.S. Patent 5,664,433 in 1997.

IDAC units, which varied in overall dimensions and other design aspects from IDEC, were produced by a Sacramento licensee and locally fabricated between 1997 and 1999. Several hundred IDACs were installed through a SMUD incentive program. We monitored four IDAC units in milder East Bay climates in 1998 for a PG&E project. Data showed the average energy efficiency rating (EER) of the IDACs to be less than half that measured with the original six IDEC's.

Due to supply limitations, IDAC was produced with an indirect heat exchanger four inches narrower than IDEC. The width of the cabinet was reduced four inches accordingly. The resulting reduced indirect heat exchanger volume and constricted internal airflow due to the reduction in both heat exchanger and internal cabinet volume may account for the performance decline. Detailed monitoring of these IDAC units in valley climates, to allow head-to-head IDEC comparison, was not undertaken. Numerous SMUD IDAC program participants reported excessive reliability failures and unsatisfactory comfort under extreme conditions. Such reports have been anecdotal, but written responses obtained in this exercise appear to support them.

Sample: In the spring of 2002, we prepared and sent users of both IDEC and IDAC Indirect/Direct Evaporative Coolers questionnaires designed to assess relative "customer satisfaction" among users of the two devices. Responding IDEC participants, located in Sacramento, Davis and Cathedral City, were three of the original six AdobeAir prototype units installed in 1994. The other three IDEC occupants could not be readily located. IDAC participants were chosen from six respondents identified by the SMUD IDAC program manager. Of the six IDACs, three sites located in central Sacramento were selected for comparison based on climate consistency. The remaining three were from outlying areas including Folsom, Orangevale and Walnut Creek.

Survey Instrument: We adapted the questionnaire from a format developed in cooperation with a research group for a satisfaction survey of advanced cooling equipment (AC2) in 1998.

Analysis: We tabulated the questions and corresponding responses of selected analysis subjects in a matrix to allow numeric assignments and calculations (Table B-1). We scored responses as follows:

1 point – positive response (satisfaction)
-1 point – negative response (dissatisfaction)
0 point – neutral response

Longevity ranking was the only exception to the single digit positive/negative scoring. On the assumption that longevity is a major indicator of, and contributor to satisfaction, we scored one point for each year the respondent unit was in service for question 3. Recognizing this may be argued to skew results in favor of the older IDEC cases, totals are calculated both including and excluding scores for question 3.

Results: Refer to Table B-1 for scoring of individual questions. Final results shown below include a total score of 78 for IDEC versus 41 for IDAC, indicating a substantially higher level of overall customer satisfaction (approaching double) among IDEC versus IDAC users.

Table B-1: Questionnaire Response Summary

	#1	#2	#3	IDEC TOT	#4	#5	#6	IDAC TOT
TOTALS (including question 3)	**26**	**25**	**27**	**78**	**5**	**22**	**14**	**41**
TOTALS (excluding question 3)				**54**				**30**

Our detailed review of individual responses underscores the dramatic difference in satisfaction perceptions between the two groups. IDEC users scored unanimously positive for key indicators including satisfaction overall, energy bill savings, cooling comfort, operating up to expectations, environmental benefits, and endorsement worthiness. The single negative IDEC response related to the installing contractors knowledge level and does not indicate any degree of dissatisfaction with the appliance. IDAC users - by striking comparison - unanimously indicated high satisfaction levels only with energy bill savings. Negative responses were registered for satisfaction overall, cooling comfort, reliability, operating up to expectations, and endorsement worthiness.

Appendix C: Diagram of Unit with Dimensions

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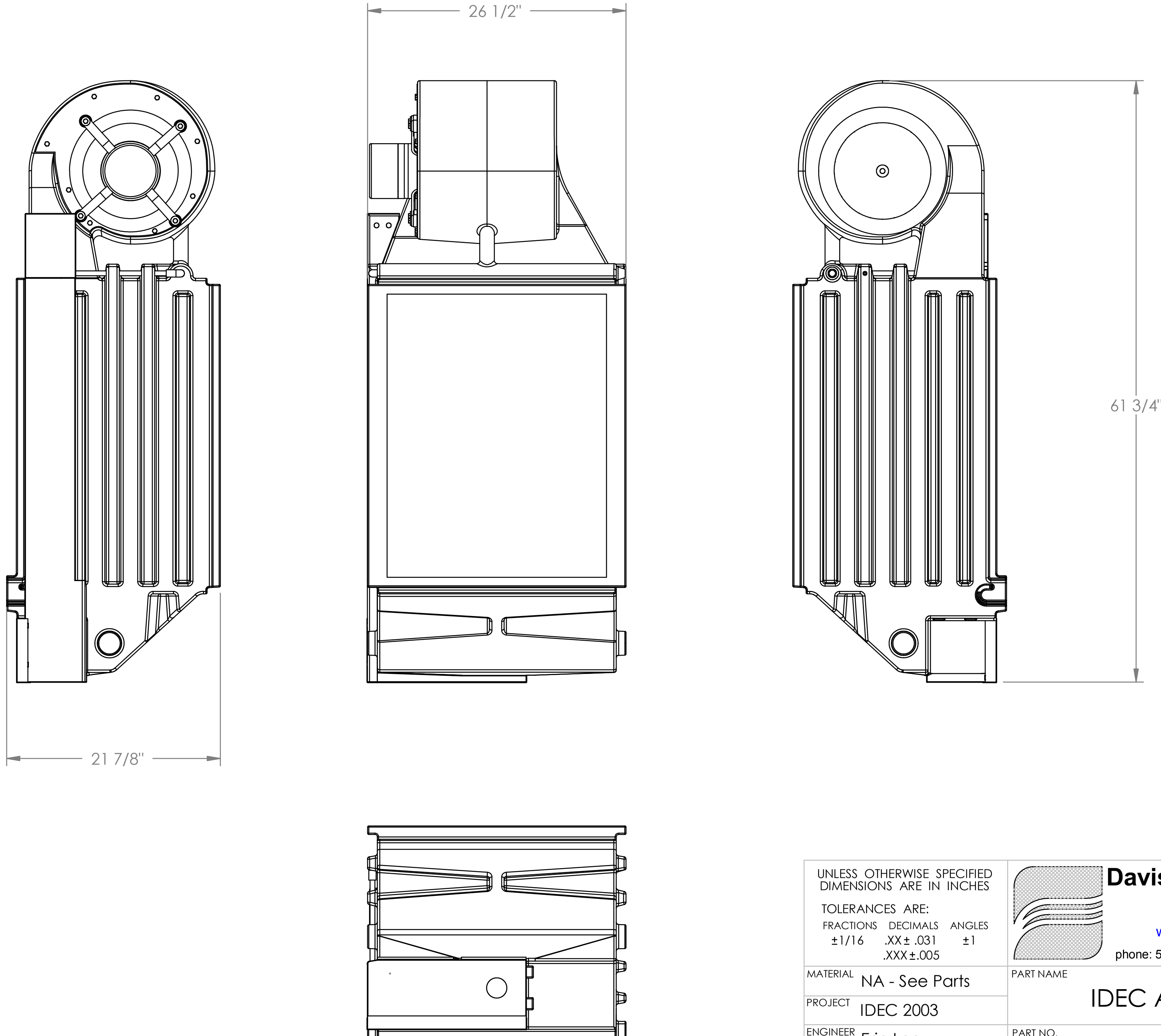

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES

TOLERANCES ARE:

FRACTIONS	DECIMALS	ANGLES
±1/16	.XX ± .031	±1
	.XXX ± .005	

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MATERIAL	NA - See Parts
PROJECT	IDEC 2003
ENGINEER	Eric Lee
DRAWN BY	Eric Lee
PART NAME	IDEC Assembly
PART NO.	208A-001
REV	A
DATE	4/1/2004
SCALE	1:15
CAD FILE	208A-001
SHEET	1 OF 1

Appendix D: Approval of Test Results

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BERKELEY LAB

29 October 2003

To Whom It May Concern:

In an effort to provide a third-party assessment of the Davis Energy Group's Generation 3 prototype IDEC testing effort, I have extensively reviewed their testing procedures, calibrated laboratory apparatus, and monitoring systems, and have found them to be appropriate. I find the attached results (Table 1) to be an acceptable summary of the laboratory tests. The overall test goal was to compare laboratory performance of the current "Generation 3" design with 1994 laboratory tests by AdobeAir for the "Generation 1" unit. The Generation 1 lab results are repeated in Table 2 for comparison.

Each results table includes five test conditions. The Generation 1 (base case) was operated in the ductless installation configuration only, with three high-speed (nominally 1550 CFM) supply air sets and one set each at medium (1250 CFM) and low (750 CFM) speeds. The Generation 3 tests include one "ductless" set each at high, medium, and low speeds, and "ducted" sets at high (1250 CFM) and low speeds. The highest attainable flow rate for the ducted configuration was 1340 CFM where capacity varied little from the 1250 CFM result, Davis Energy Group has therefore defined 1250 CFM as "high speed" for the ducted configuration.

IDEC system effectiveness, defined as the percentage equivalent of total temperature drop (inlet air minus supply air dry bulb temperatures) divided by wet bulb depression (inlet air dry bulb minus inlet air wet bulb temperature), is the applicable performance measure. The results showing effectiveness ranging from 109% at ductless high speed to 116% at ducted low speed appear sound based the measurements using the calibrated instruments that I inspected.

The Generation 3 data represent 50-minute test periods for the ductless 1550 and 1250 CFM tests and 20-minute test periods (begun after data stabilized at each setting) for the other three tests.

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Although it would be preferable that all data were from stable test periods greater than twenty minutes, I understand that the test schedule was constrained by available weather. The 50-minute tests show relatively consistent effectiveness, and I believe that the twenty-minute data adequately represent steady-state operation.

In summary, the data indicate that total IDEC effectiveness for a ducted system is in excess of 115%. Ducted installation is preferred for many applications including relocatable classrooms. The capacity, energy efficiency, and 100% outdoor air feature of this unit should be quite attractive to school districts. The ductless operation was observed to have total effectiveness above 109%. Overall, the new IDEC design exceeds the project performance goal, and appears to be ready to proceed to the next stage towards production. It will be valuable in the future to derive field data and additional lab data, preferably from an independent laboratory, for production units.

Sincerely,

Mike Apte, Staff Scientist
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Lawrence Berkeley National Laboratory.
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Berkeley CA 94720
510-486-4669
MGApte@lbl.gov

Table 1.Generation 1 IDEC testing results completed at AdobeAir, July 1994.

Simulated Installation>>	***Ductless***				
	High Speed	**High Speed**	**High Speed**	**Medium Speed**	**Low Speed**
Fan Power, Watts	610	609	620	325	74
Total Power, Watts	<--------------not reported-------------->				
Supply cfm	1579	1533	1566	1256	738
Secondary cfm	485	507	493	405	236
Entering Air Dry Bulb, °F	102.6	92.3	102.5	98.2	100.4
Entering Air Wet Bulb, °F	73.0	69.9	72.3	71.4	72.9
Between stage Dry Bulb,°F	<--------------not reported-------------->				
Leaving Air Dry Bulb, °F	71.5	68.8	70.7	69.3	69.7
Leaving Air Wet Bulb, °F	68.8	66.3	67.2	66.8	68.1
Indirect Effectiveness, %	49.0%	50.4%	55.3%	57.5%	57.5%
Direct Effectiveness, %	86.0%	83.0%	81.2%	84.4%	90.3%
Total Effectiveness, %	105.1%	104.9%	105.3%	107.8%	111.6%
Capacity, Btu/hr	<--------------not reported-------------->				
Capacity, tons	<--------------not reported-------------->				
EER	<--------------not reported-------------->				

Table 2.Generation 3 (current design) IDEC testing results completed at Davis Energy Group laboratory. High and Medium speed Ductless tests are from 27 October 2003 results, with approximately 60- and 45-minute data, respectively. The other 3 sets are 20-minute data collected on 21 October 2003.

Simulated Installation>>	***Ductless***			***Ducted***	
	High Speed	**Medium Speed**	**Low Speed**	**High Speed**	**Low Speed**
Fan Power, Watts	498	266	58	445	110
Total Power, Watts	521	289	81	468	133
Supply cfm	1551	1251	750	1250	750
Secondary cfm	622	478	250	800	490
Entering Air Dry Bulb, °F	104.7	103.7	104.3	103.1	106.5
Entering Air Wet Bulb, °F	70.8	71.1	73.0	73.3	74.3
Between stage Dry Bulb,°F	87.0	85.0	84.5	80.5	82.9
Leaving Air Dry Bulb, °F	67.8	67.8	68.8	68.7	69.1
Leaving Air Wet Bulb, °F	65.0	65.3	67.2	66.6	67.5
Indirect Effectiveness, %	52.2	57.2	63.3	75.7	73.3
Direct Effectiveness, %	87.1	87.4	91.0	84.8	89.6
Total Effectiveness, %	108.9	110.1	113.6	115.3	116.2
Capacity, Btu/hr	20,660	17,155	11,128	19,257	11,770
Capacity, tons	1.72	1.43	0.93	1.60	0.98
EER	40	59	136	41	88

Appendix E: Detailed IDEC Test Plan

PIER/ICM Project – CEC Contract 500-98-022

Development of an Improved Indirect-Direct Evaporative Cooler

Subtask 2.4 Test Plan

Davis Energy Group

April 28, 2003 (updated Oct. 1, 2003)

1 BACKGROUND AND OBJECTIVES

1.1 Background

The Indirect-Direct Evaporative Cooler (IDEC) is a high efficiency two stage evaporative cooler intended to replace conventional residential vapor-compression air conditioners in dry climates. This test plan summarizes the proposed IDEC test setup and plan. All testing will take place at the DEG laboratory in Davis.

1.2 Objectives

The goal of this testing is to obtain accurate performance data for the revised IDEC design. Tests will be conducted that determine IDEC evaporative effectiveness, capacity and energy efficiency ratio (EER) under various outdoor air conditions. Both ducted and unducted installations will be simulated in the tests. From the test results we will recalibrate the IDEC simulation model to allow comparison to prior IDEC performance at any specified outdoor air conditions.

2 STRATEGY

2.1 General Monitoring and Evaluation Strategy

The general monitoring strategy is to monitor IDEC energy performance and water use during warm weather in Davis. We will operate the unit at each of three blower speeds with and without imposed external pressure drop to derive data through a range of possible conditions. We will monitor dry and wet bulb temperatures for outdoor, supply, and exhaust air streams, dry bulb temperature between the stages, and airflow at supply and exhaust outlets. We will also monitor total power to facilitate efficiency calculations. The resulting data should facilitate efficiency calculations and comparisons to prior test results.

2.2 Definitions and Abbreviations

Specific monitoring data points to be collected and values to be calculated include:

Data Point	**Abbr.**	**Description.**
Exhaust Airflow	FAE	The airflow exhausted from the secondary heat exchanger passages
Exhaust Air RH	RHE	Relative Humidity at the exhaust of the wet side of the indirect stage.
Exhaust Air Temperature	TAE	Dry Bulb temperature of the air at the exhaust of the wet side of the indirect stage.
Fan Energy	E_{FAN}	Energy consumed by supply blower.
Flow Rate	FLG	Water flow rate to the evaporative media.
Indirect Outlet Air Temperature	$TAI_{DB,i}$	Dry Bulb temperature of the air at one of nine thermocouple junctions (denoted by *i*) at the outlet of the dry side of the indirect stage.
Indirect Stage Evaporative Effectiveness	EFF_{ind}	The evaporative effectiveness of the indirect stage only.
Outdoor Air RH	RHO	Relative Humidity of the outdoor air.
Outdoor Air Temperature	TAO_{DB}	Outdoor Dry Bulb air temperature (also known as inlet air temperature)
Outdoor Air Wet Bulb Temperature	TAO_{WB}	Wet Bulb temperature of outdoor air calculated from TAO_{DB} and RHO
Power	P_{tot}	Total unit power.
Pump Energy	E_{PMP}	Energy consumed by water pump.
Sump Temperature	TWS	Water temperature in the reservoir.
Supply Airflow	FAS	The airflow into the building from the direct stage outlet
Supply Air RH	RHS	Relative Humidity of the supply air at the outlet of the direct stage.
Supply Air Temperature	TAS_{DB}	Dry Bulb temperature of supply air (at the outlet of the direct stage).
Supply Air Wet Bulb Temperature	TAS_{WB}	Wet Bulb temperature of supply air calculated from TAS_{DB} and RHS
Total Energy	E_{TOT}	Energy consumed by entire IDEC unit.
Total Evaporative Effectiveness	EFF_{tot}	The total evaporative effectiveness of the IDEC based on outside air conditions.

2.3 Test Setup

The IDEC tests will be performed at the DEG laboratory in Davis, CA. The unit is installed in a through-the-wall configuration, with access to both sides. Plenums built for the inlet, exhaust and supply facilitate accurate temperature, RH, and flow readings at these points. The supply plenum is equipped with a "blower door" device and the exhaust plenum is equipped with a "Ductblaster" unit. These components accurately measure airflow and permit pressure adjustments to either balance their imposed pressure drops or simulate higher pressure drops caused by ducts and registers. A thermocouple grid with sensors in the dry passages just upstream of the indirect/direct stage transition zone facilitates evaluation of indirect stage evaporative effectiveness.

2.4 Data Acquisition Approach

The monitoring system includes two DT50 dataloggers, the blower door and Ductblaster units, an APT pressure logger to record airflow, three temperature/RH sensors (two duct, one outdoor), ten thermocouples, one flow meter and three power meters. This equipment will be further discussed in section 3.

Temperature and humidity values are scanned every 6 seconds, averaged and recorded every 30 seconds. The APT pressure logger is programmed with a similar scanning rate for easier correlation during analysis.

The data will be downloaded after each test and the memory card erased to make room for the new data.

2.5 Test Sequences

We will test the unit for at least six days, for six hours each day. During the first three hours of each day of testing, we will run the unit as specified in Table 1. In the remaining hours of each test day we will test the unit at supply air flow rates of 750, 1250, and 1550 cfm in half hour intervals. For each day, the unit will be run in conditions to simulate either ductless or ducted installations, as specified in Table 1.

Table 1 – Tests to be performed.

Day	Supply Air CFM, first three hours	Pressure Drop
1	750	Ducted
2	750	Ductless
3	1250	Ducted
4	1250	Ductless
5	1550	Ducted
6	1550	Ductless

3 PERFORMANCE PARAMETERS TO BE EVALUATED

3.1 Evaporative Effectiveness (Saturation Efficiency)

3.1.1 The total evaporative effectiveness of the IDEC is of primary interest in this study. 2-stage evaporative coolers have demonstrated greater than 100% evaporative effectiveness in laboratory tests and theoretical models. This value will be calculated for several sets of conditions (varying airflow and wet and dry bulb temperatures, see section 2.5) to determine average and worse case scenarios. The equation for the total evaporative effectiveness is:

$$EFF_{tot} = \frac{TAO_{DB} - TAS_{DB}}{TAO_{DB} - TAO_{WB}}$$

As a check, this parameter will also be calculated with the outdoor wet bulb temperature as determined by referencing TAO_{DB} and *RHO* on the ASHRAE Psychrometric Chart No. 1.

3.1.2 Also of interest is the evaporative effectiveness of the indirect stage. This stage should introduce no moisture to the air that passes through the dry passages, performing only sensible cooling, and dropping the wet bulb temperature. The runs where only the indirect stage is operating will allow us to determine that it is operating correctly and adding no moisture. The temperature and RH values from these runs will also allow us to calculate the evaporative effectiveness of our indirect stage with the following equation:

$$EFF_{ind} = \frac{TAO_{DB} - TAI_{DB}}{TAO_{DB} - TAO_{WB}}$$

As a check, this parameter will also be calculated with the outdoor wet bulb temperature as determined by referencing TAO_{DB} and *RHO* on the ASHRAE Psychrometric Chart No. 1.

3.2 Capacity

Since the IDEC is a 100% outdoor air cooling system, its capacity must be determined based on the mass flow rate and the temperature difference between air leaving the conditioned space and IDEC supply air. We will compute capacity based on Sacramento design conditions and 78° dry bulb indoor design temperature based on the following equation:

$$q_s = \dot{Q} \times \rho \times c_p \times (TAR_{DB} - TAO_{DB} + EFF_{tot} \times (TAO_{DB} - TAO_{WB}))$$

3.3 Energy Efficiency Ratio (EER)

We will calculate EER using the rated capacity "q_s" based on the equation below. We will also compute "effective EER" based on assumed latent, infiltration, and ceiling load reductions

$$EER = \frac{q_s}{P_{tot}}$$

4 MONITORING SYSTEM DESIGN

4.1 Datapoints

Table 2 – Datapoints to be monitored in this test.

Point	Sensor			
No.	Variable name	Description	Signal	Accuracy (+/-)
1	FAS	Supply air flow rate	APT (internal)	3%
2	FAE	Exhaust air flow rate	APT (internal)	3%
3	TAO	outdoor temp.	RTD, 4-20mA	0.06%
4	RHO	outdoor air RH	RH, 4-20mA	2%
5	TAI	indirect outlet air temp	RTD, 4-20mA	0.06%
6	RHI	indirect outlet air RH	RH, 4-20mA	2%
7	TAS	supply air temp	RTD, 4-20mA	0.06%
8	RHS	supply air RH	RH, 4-20mA	2%
9	TAE	secondary passage exhaust temp	RTD, 4-20mA	0.06%
10	RHE	secondary passage exhaust RH	RH, 4-20mA	2%
11	TWS	sump water temp	Type T therm.	0.75%
12	FLG	water consumption	0-15VDC pulsed	2%
13	EFAN	fan energy	Pulse	0.05%
14	EPMP	pump energy	Pulse	0.05%
15	ETOT	total energy	Pulse	0.05%

4.2 Datalogger Specifications

Each Data Electronics DT50 features 5 double-ended/10 single-ended analog channels, five digital I/O channels, and three counters. Detailed specifications are provided in Appendix A.

4.3 Airflow Measurement

Airflow measurement will be calculated from pressure differentials through orifices of known areas. An 8 channel APT pressure datalogger will be used to record values. This is a separate, stand-alone, instrument, programmed separately from the DT50s.

4.4 Sump Water Temperature

The temperature of the water in the sump is measured using an immersion type Type-T thermocouple.

4.5 Wet Bulb Air Temperature Measurement

Wet bulb air temperatures are directly measured by moving air over RTDs shrouded in wet cotton wicking socks as per the measurement standard in ASHRAE 41.1.

4.6 Dry Bulb Air Temperature and Relative Humidity Measurement

Dry bulb air temperature and relative humidity values are measured using Vaisala HMD 60Y combination temperature/RH sensors. These sensors both send 4-20mA signals to the datalogger. These are powered with 24VDC.

4.6 Water Consumption Measurement

Water consumption is monitored indirectly by measuring cycles in sump temperature (which define refill events). Total water used is then computed using sump volume parameters.

4.7 Power Consumption Measurement

The energy consumption measurements are performed using Continental Control Systems WNA-1P-240P power monitors and 30A current transducers.

5 MONITORING SYSTEM INSTALLATION

5.1 Installation of Datalogger

The datalogger is mounted next to the IDEC in a 12” by 24” by 4” electrical panel along with terminal strips and a power strip for the DT and the powered sensors.

5.2 Commissioning and Calibration

A commissioning log will be completed before the testing begins. This log will include the date calibrations were performed and the sensor calibration values.

5.3 Monitoring Log

A monitoring log will be kept on site to record any changes to the test or the monitoring system, including changes to the computer programs.

6 DATALOGGER PROGRAMMING

Data points will be sampled at a rate of 15 seconds, and averaged for 6 minutes. Points 1 and 2 on Table 2 will be recorded using the APT pressure datalogger, and the remainder of the points will be recorded by the DT50.

7 DATA ACQUISITION

7.1 Data Collection

Because the warehouse is in close proximity to the office, the data will be downloaded manually and transferred to the DEG office LAN by floppy disk. The data will then be screened and analyzed. Data will be collected and the card erased at the end of each test.

7.2 Data Format and Storage

Data are logged in comma-delimited ASCII format by the DT50. The files will be stored on the DEG server, which is backed up monthly.

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