Taking a Building's Vital Signs: A Lending Library of Handheld Instruments

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It's 10:00 PM. Do you know what your building is doing? Is the economizer set to maximum outside air? Has the lighting control system, be it human or machine, switched circuits off in unoccupied areas? What percentage of your personal computers is running?

When it comes to buildings, lack of knowledge usually means wasted power and energy. Few building owners realize precisely how their building systems operate. Over time building systems degrade, or worse, never perform as designed. An instrumented diagnostic examination rarely fails to identify energy conservation opportunities.

In late 1993, a large California electric utility company launched a tool-lending library to assist building managers and design professionals in measuring the real-time performance of their buildings. This service offers access to hand-held instruments, dataloggers, and technical support. The library's instruments have proven useful in discovering control problems, in isolating systems and equipment responsible for excessive demand and energy use, and in providing measured baselines for energy-conserving retrofits. The service has been augmented by application-specific training seminars, guidelines and software tools.

This paper presents two years of experience with the tool-lending library and describes the intent and context of the lending library's approach, results from field applications in the form of case examples, and lessons learned in the early years of the program's operation.

INTRODUCTION

In the 1985 film *Brazil* director Terry Gilliam presents a dark, comedic portrait of future building technology (Gilliam, 1985). Set sometime in the 21st Century, Brazil's building systems are too complex for a layperson's comprehension and seem largely out of control. The film's visual references to interstitial space show a tangle of ducts, wires, and pipes so compressed they spill into occupied rooms. Occupants despair for control over their immediate surroundings and seem deprived of the most basic amenities. Maintenance is particularly nightmarish with an uncaring, bureaucratic ''Central Control'' so concerned with paperwork that citizens have little hope for effective repair. Robert DeNiro is cast as Harry Tuttle, the film's heroic figure. Tuttle appears from the dark night as a covert, a Ninja-like HVAC expert who unfolds his toolkit and quickly repairs failed systems. In the movie, Tuttle's sensible repair skills have been criminalized and he must constantly evade authorities while effecting repairs.

Figure 1. *Robert DeNiro as Harry Tuttle. Says Tuttle, the insurgent HVAC repairman in* Brazil, *about his lawless repair of HVAC systems: ''we are all in this together.'' Source: Universal City Studios.*

The images in *Brazil* are particularly telling for those of us involved in the design and operation of buildings. The theme of building technology out of control resonates, however slightly, with our contemporary circumstances. Compared to even twenty years ago we now have substantially more complex building systems and more finely-defined, compartmentalized roles for building professionals. The appearance of *Brazil*'s theme in the popular media speaks also to the broader perceptions of building users and their uneasy familiarity with the processes of building commissioning and operation. It is not difficult to imagine that an appreciable number of *Brazil*'s viewers yearned for their own Ninja repairman to make things right with a recalcitrant device.

This paper describes a program that lives in the spirit of Harry Tuttle: a utility Energy Center Tool Lending Library (the Toolkit) that loans diagnostic tools to the designers and operators of buildings. Where necessary the program provides instruction and project-specific assistance. The intent is to provide building professionals with access to a new generation of measurement devices and in doing so to empower those on the building front lines to diagnose cases of poor performance as a first step toward remedy. The devices can profile the local environment from either an engineering or qualitative point of view over time frames ranging from single snapshots to several months.

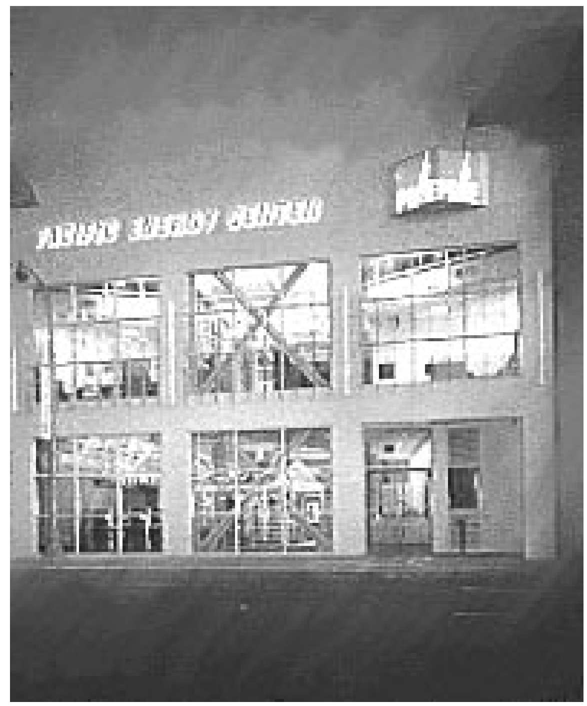
Program Context

For nearly twenty years, electric utility rebate and conservation efforts have focused on new technologies that replace existing equipment with components requiring less power. Fluorescent lamps and electronic ballasts, higher-efficiency chillers and motors have been easily-spotted as conservation opportunities. Now that these technologies are well understood and their energy savings validated, there are fewer ground-breaking technologies promising dramatic energy savings on the horizon, though incremental improvements in existing equipment will continue.

Still, one area of promise lies in the information-based technologies such as control and measurement systems. Here energy savings are often unrealized because they lie hidden. The utility believes that providing customers and consultants with easy-to-use equipment for measuring actual system performance can lead to the discovery of new opportunities and practices that can lead to substantial savings, often without the installation of new equipment.

The notion of a lending library of building measurement instruments was developed during the early programming stages of the Energy Center (EC). This was imagined to be a novel service, geared toward the quick assessment of building performance by those already familiar with the building. The medical parallel would be taking a patient's vital signs, a diagnostic process of quickly assessing key parameters. In a similar fashion, the Toolkit program is geared toward a quick, relatively informal evaluation of building performance. Its activities occur at a different scale than the more detailed assessments common to DSM verification programs or Building Science research projects (Haberl et al. 1996; Herzog & LaVine 1992). A shared use or ''library'' concept seemed to make the most sense with equipment housed, maintained and distributed by the Energy Center.

Figure 2. *The Energy Center. Opened in 1991 by a large California utility company, the facility is a DSM resource for building designers and operators (Bryan 1993). From its earliest programming in 1989, plans called for the development of an instrument lending program.*



The initial development phases of the tool lending library involved (1) defining the opportunity; (2) identifying appropriate measurement tools for building applications; (3) testing equipment and developing protocols for their use; (4) implementing educational programs that attracted and trained potential users; and (5) providing project-specific advice. The initial set of Toolkit instruments was based on an equipment set developed by the Vital Signs Project, a separate curriculum materials project based at the Energy Center (Benton & Kwok 1995). Equipment is loaned without direct charge to customers and consultants doing business in the utility's Northern California service territory. Policy requires that use of equipment is directed toward issues of energy conservation (Newcomb & Gustafson 1994).

Toolkit Devices

The Toolkit offers devices ranging from simple single-channel temperature loggers to ultrasonic flow measurement sensors. In aggregate they offer the ability to measure building performance at both the system and component level. The program's measurement instruments are tools of translation. They dispassionately convert aspects of the physical environment into numbers describing the ebb and flow of energy through the time and space of buildings. These numbers can be interpreted in the context of abstract codes & standards and a growing body of knowledge concerning human performance in the physical environment. Here reasonable values and absolute limits are established for many of the measurable aspects of buildings. Beyond these numbers, however, lies the intent of design. Our intent in designing for a particular interior air temperature or luminance ratio is not the flexing of technological prowess required to achieve these targets but rather attending to the comfort and well-being of building occupants. In most circumstances physical measurements also represent forces associated with more general qualities of a space. Instruments capture patterns that can help shape a building professional's intuitive sense of the experiential environment as well as provide more conventional measures of quantitative performance.

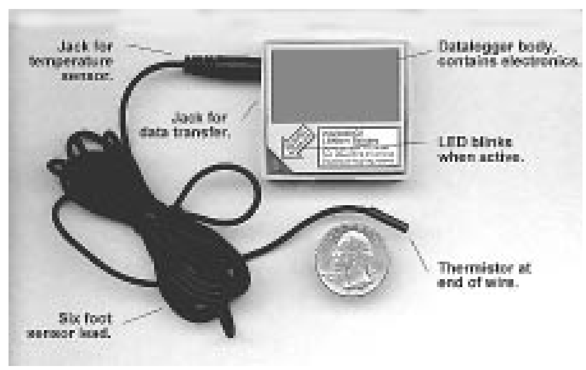
Like many aspects of modern life the technology of measurement has been changing rapidly. In particular, the microprocessor and digital displays have combined to make instruments more capable and easier to use. The instruments comprising the Toolkit fall in to the broad classes of handheld instruments, micro dataloggers, data acquisition systems, and sensors.

Handheld instruments are portable devices designed primarily around the task of collecting ''snapshot'' sample readings. The Toolkit has handheld instruments for the measurement of air temperature, surface temperature, globe temperature, relative humidity, air velocity, pressure, illuminance, luminance, electric current, electric power, voltage, EMF, CO_2, and other variables. Most handheld instruments now include microprocessors for the acquisition, scaling, and display of measurements. This approach often allows the recording of minima, maxima, and means for longer periods. In addition, many of the Toolkit's handheld instruments provide a DC voltage output signal to allow the recording of continuous readings if desired.

Figure 3. *Example Handheld Instruments, in this case photometers, from the Toolkit Program. Clockwise from the upper left: (1) a luminance meter, (2) an illuminance micro datalogger, (3) an inexpensive photometer, (4) a photometer with traceable calibration that serves as an in-house reference, (5) a multi-channel datalogger polling eight miniature photometers, and (6) an extended range photometer.*

Micro dataloggers constitute a new class of measurement device that combines a sensor, an inexpensive single-channel analog-to-digital converter, non-volatile memory, and a computer interface. The resulting device, sometimes as small as a matchbox, can record readings for temperature, humidity, illuminance, pressure, or voltage at regular intervals (say five minutes) for periods of weeks. Once programmed through a simple microcomputer interface, the micro dataloggers are autonomous and can easily be placed in survey locations.

Figure 4. *A Single-Channel Temperature Logger. The device provides a programmable digital temperature recording capability for less than $100 and is compellingly simple to use.*



Data acquisition systems are generally more capable, multi-channel data recording systems that offer programmability and precision. These devices allow the packaging of data collection software into an automated process requiring little specialized skill on the user's part. In addition, collected data are delivered to an associated laptop computer where standard pre-programmed routines can regularize the data analysis phase. Contemporary data acquisition systems are much like a Swiss Army knife, collecting a versatile set of tools in a compact, battery-powered package that is useful with a modest amount of training.

Sensors in the EC Toolkit provide input options for the data acquisition systems. For example, these include devices for the measurement of illuminance, radiation, fluid flow, pressure, temperature, occupancy.

to-day operation and strategic review, is the source of the instrument usage patterns cited in this paper.

Table 1. *Sample Instruments from the Lending Library*

Model	Item	Measures	Quantity	Unit Cost (Approx.)
A60FL	ACR A60FL Clamp-on current trans.	Current in amps	42	$75
SR-002	ACR Smartreader 2 (temp & RH)	Temp, RH in °F, °C, %	4	$669
SR-003	ACR Smartreader 3 (electric current)	Current in amps	8	$582
201	AEC MicroDatalogger	Records varied inputs	16	$995
21X	Campbell Scientific 21X DAS	Records varied inputs	4	$981
Y8101	Fluke Clamp-on current transducer	Power	4	$62
Fluke 33	Fluke RMS current meter	Current in amps	4	$235
Fluke 87	Fluke RMS multimeter	Measures varied inputs	4	$292
80T-150U	Fluke Temperature Probe	Temperature in °F, °C	2	$108
Telaire	Gaztech CO_2 monitor	CO_2 in ppm	5	$450
9105	Hart Scientific Dry-Well Calibrator	Temperature in °F, °C	1	$4,700
LI-210SA	Li-Cor 210S photometer	Illuminance in lux	16	$275
LI 200SA	Li-Cor Silicon pyranometer	Solar radiation in w/m^2	4	$160
1842-155	Minolta LS-100 luminance meter	Luminance in cd/m^2	2	$2,995
1519-911	Minolta T-1H illuminance meter	Illuminance in lux	3	$810
OS81	Omega portable pyrameter (infrared)	Surface temp. in °F, °C	2	$856
Hobo-Light	Onset Hobo light intensity loggers	Illuminance in lux	130	$123
Hobo-RH	Onset Hobo relative humidity loggers	Relative humidity in %	35	$144
Hobo-Volt	Onset Hobo voltage loggers	Voltage 0-2.5 VDC	96	$106
Hobo-XT	Onset HoboTemp temperature loggers	Temperature in °F, °C	400	$96
6T102	Raynger Raytek Pyrameter	Surface temp. in °F, °C	1	$1,145
429	Solomat Digital Hotwire Anemometer	Air velocity in fpm, m/s	3	$412
1328	Taylor sling psychrometer	Dry bulb & wet bulb temp	2	$85
99/PMS3	Ultrasonic Controlotron	Fluid flow	1	$1,250

Accrued experience has led to refinement of the Toolkit's components. Table 1 provides a sample listing of devices available for loan.

While all of the Toolkit's devices are useful instruments, some are more popular than others. In approximately two years of operation the Toolkit program has made 1148 instrument loans. The most requested devices have been the micro dataloggers with 364 loans involving single-channel devices and 157 loans of the three-channel current dataloggers Other popular instruments include illuminance meters, a custom-designed occupancy logging system, handheld current meters, CO_2 meters, and handheld temperature meters.

To help in tracking the instruments the EC staff developed a microcomputer database system that registers each loan, maintains inventories, and handles routine instrument-related correspondence. This database, invaluable for day-

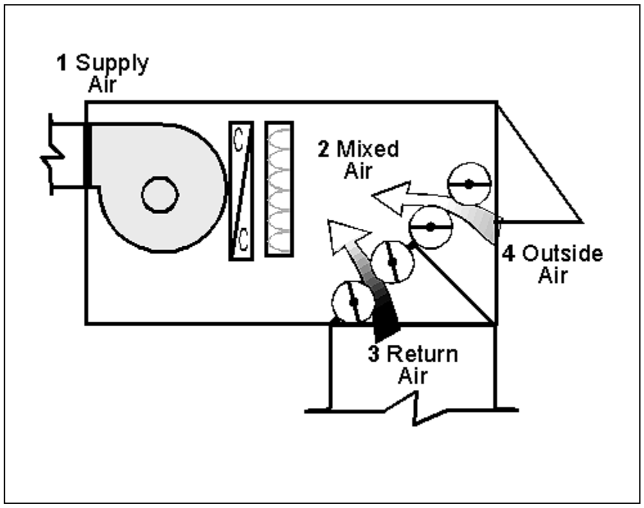
TRAINING AND TECHNICAL SUPPORT

The Toolkit program is run by the equivalent of two half-time persons on the EC technical staff. To leverage their efforts we have developed materials and programs which support customers in the knowledgeable use of the Toolkit devices. These include detailed application notes, automated spreadsheets for analyzing data, hands-on workshops, and one-on-one consulting services.

Application Notes

Application notes are succinct written documents providing general information on data collection, specific information on the Toolkit's data collection equipment, and suggestions for specific data collection applications. In essence, the program's most frequently asked questions guide the development of handouts to cover Toolkit topics. At this writing the program has fourteen application notes with topics like Preparation Notes for Field Data Collection, Using Watt Transducers, and Evaluating Air-Side Economizers.

Figure 5. *Schematic of an Air-Side Economizer. The numbers indicate locations of four temperature sensors placed to profile operation patterns.*



Automated Spreadsheets

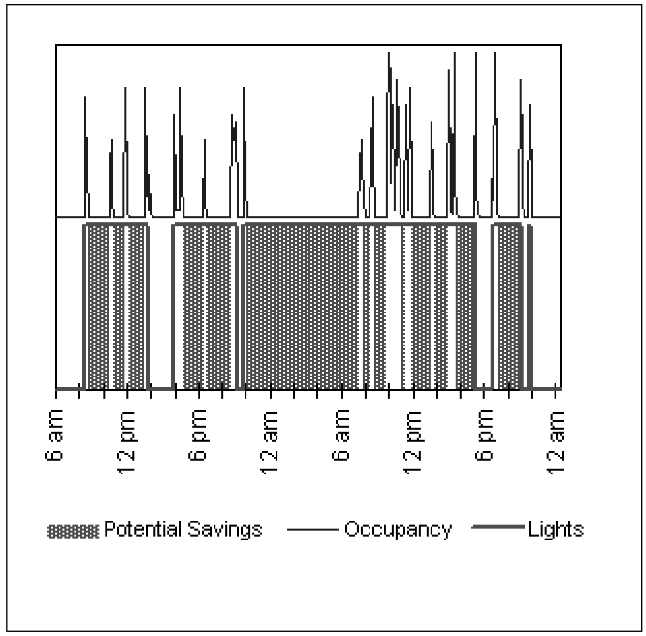
Due both to the limitations in the datalogger programs and the complexity of training customers to use features of disparate programs, the Toolkit program has standardized on microcomputer-based spreadsheets for data visualization and analysis. Frequently requested procedures are served by several automated spreadsheets that assist in handling and analyzing collected data. Examples include:

EC Power. This spreadsheet uses either the pulse or analog output from a single-point, true RMS power transducer. From the data, the spreadsheet reports maxima for power and energy over a selected period as well as displaying a graph of power as a function of time.

EC Light. Our most automated spreadsheet, EC Light assists in the process of prospecting for lighting control savings using scheduling or occupancy-sensing controls. The process involves collecting data from single-channel dataloggers to monitor the functions of occupancy and lighting use in a candidate space. The spreadsheet then automates the importation of collected data, prompts the user for scheduling information, and then applies control functions to the actual room data. The program then reports the incremental savings (or costs) that would be realized by retrofitting scheduling or occupancy-sensing controls.

Figure 6 shows data collected over a two day period in a storage room. The upper line indicates occupancy as detected by a motion sensor, the lower line indicates the status of the lights , and the solid areas show times when an occupancy sensor could have turned the lights off to save energy (25.4 hours in this two day period). Note that the lights were sometimes turned off as people left, but more often they were left on, including a period of nearly 10 hours overnight.

Figure 6. *Occupancy Sensor Prospecting*



EC Cool. This spreadsheet imports data from four single-channel temperature loggers representing outside air, return air, mixed air and supply air. From these data it develops graphical presentations that can be used to evaluate air-side economizer operation (see case study).

The Toolkit Workshop Series

Over the last four years, the EC has offered over 400 workshops and lectures related to building energy efficiency. Part of this effort is a developing series of training (and marketing) workshops based on Toolkit application topics. The most popular offerings in this area include: (1) Measuring Power and Energy, (2) Evaluating HVAC Controls, and (3) Evaluating Lighting Controls.

Each workshop features one of our small pocket or multi-channel dataloggers and includes exercises in launching (datalogger configuration), field deployment, data downloading and data analysis. The workshops are typically three hours long and limited to 24 participants. In order to support a meaningful hands-on experience there are no more than four participants per computer and the workshops are staffed with three instructors. Also offered is an optional, 90-minute ‘‘Basics of Data Acquisition’’ session before each workshop for those desiring an overview of datalogger fundamentals. The Toolkit workshop series has been very popular and several unscheduled sessions have been held to accommodate overflow.

The workshop series contributes to the general data collection expertise of our customer base while also advertising our program. Attendees include building operators, design professionals, energy consultants, and data collection professionals. Most of the firms that provide measurement and evaluation services to the utility have sent members of their staff to our sessions.

Like the application notes and automated spreadsheets, each workshop has scripted exercises that have been used as stand-alone documents to familiarize clients with our equipment. In fact, Toolkit users seem particularly appreciative of the workshops’ supporting materials (e.g.; handouts, manufacturers’ literature, software.)

Project-Specific Advising

The final and most detailed form of assistance to Toolkit users is direct project-specific advice. The majority of our customers require some degree of assistance. This category runs the gamut from helping customers define the data collection experiment to details of spreadsheet analysis of the data. In general advising activities, provided via telephone, e-mail and in person, have been as diverse as the knowledge base of our clients. In a typical week will involve the framing of field studies including the selection of equipment, determination of data collection specifics (sampling rate, storage interval and study period), and suggestions for analysis of the data.

EARLY RESULTS FROM THE TOOLKIT PROGRAM

A retrospective view of Toolkit users finds that that it has served the audience originally targeted by the program. The majority of users have been building professionals responsible for building operation including utility staff and the staff of utility customers. In addition, design professionals from engineering, architecture, lighting design, and energy consulting practices have made constructive use of the service. We anticipate more use by designers as the EC Toolkit Workshop series continues. At a secondary level, the Toolkit provides examples for a number of the utility’s education programs and, when not otherwise committed, are used by education institutions in the utility’s service territory.

Examples of Toolkit Use

During the last two years we have been gathering notes on customers’ applications involving the devices in the Toolkit. These have been entertainingly varied and range from exercises of personal discovery to the dispassionate assessment of component performance. The following examples come from the more applied end of the spectrum and represent example applications that either have led or might lead to significant energy savings. We continue to track these case studies with understandable interest in the actions subsequently taken by Toolkit users. We note, however, that there is often a time lag between initial instrumented explorations of building performance and eventual building modifications. Thus action is still pending on some of our case studies.

Evaluation of Comfort and Energy Use in a Bowling Alley. A comprehensive energy use and comfort study employed single channel dataloggers to measure temperature, light intensity, current and CO_2 over a month’s period. The data were used to tune a DOE2 simulation of the facility. The DOE2 model was then used to evaluate a package of measures for retrofit. The CO_2 sensor was employed for evaluation of air quality at occupant height in lounge and seating areas. CO_2 concentration data coupled with smoke tests demonstrated that the present ventilation system was not effective in diluting the air in the lounge and seating areas. The proposed retrofit included rebalance of the packaged rooftop air-conditioning units together with installation of new exhaust grilles. This study was performed by an energy consultant.

Evaluation of Chiller Performance in a Major Hotel. A four-channel datalogger with true RMS watt transducers was employed to develop a three-week operating profile of a 250-ton chiller for evaluation of variable speed drive retrofit potential. The power data were used to estimate loads (tonnage) using a DOE2 model of a similar machine, and the resulting load profile was used to calculate the energy usage of a chiller with variable speed drive using a second DOE2 chiller model. The variable speed drive was estimated to reduce the energy usage by 20% during the three-week test period. The equipment was loaned to the chief building engineer and the EC staff assisted him in the analysis.

Submetering Operation of Printing Press Equipment. A multi-channel process datalogger with a true RMS watt transducer was employed to develop five-day profiles of press operation. Two actions resulted: (1) A failed relay (never shut off) was replaced on a 4.5 kW heater, and (2) submetered data led to the retrofit of two presses with variable speed drives. The project was initiated by a utility sales representative at the request of the customer.

Submetering Operation of Injection Molding Equipment. A multi-channel process datalogger with a RMS watt transducer was employed to develop three-day profiles of 12 injection molding machines. The submetered data provided impetus to retrofit all 12 machines with variable speed drives. The estimate savings were $36,000/yr from a reduction of 6,000 kWh/yr and 60 kW peak. The project was initiated by a utility sales representative at the request of the customer.

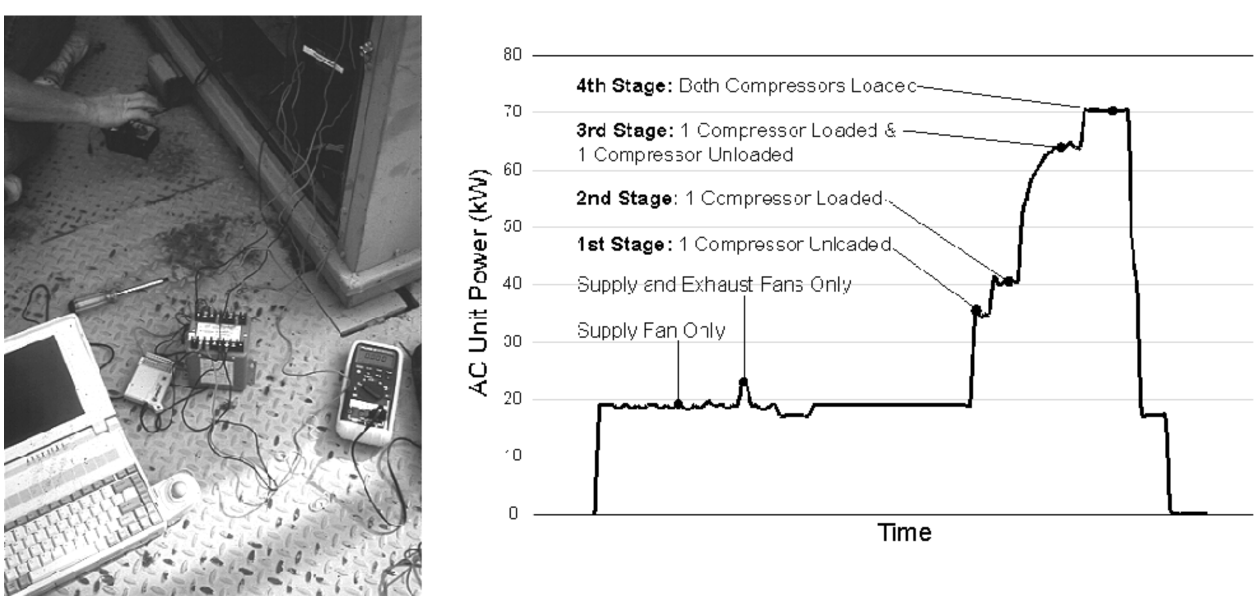
Evaluation of a Continuously-Dimming, Daylight-Following Lighting Control System. A university client had 40,000 ft^2 of studio space with daylight-following and occupancy-sensing controls on overhead, direct fluorescent fixtures. Performance of the control system had not been checked for a two-year period. Three-channel current dataloggers were used to collect time-series readings for 10 representative lighting circuits over a one-month period. The resulting data indicated that both systems were out of tune due to occupant intervention with a resultant loss of savings. The systems were retuned with attention to the factors that contributed to occupant dissatisfaction. Continued monitoring revealed that the readjustment of occupancy sensors and dimming settings reduced lighting energy use by 28% during the month following adjustments. A subjective survey of studio occupants (n = 81) indicated that the qualitative problems were corrected.

Major Retail Store Evaluation of Statewide Occupancy Sensor Retrofits. The energy manager for a major retail store chain was in the process of retrofitting occupant sensor controls in the storerooms of all of their California stores. He approached the Toolkit program to perform an in-situ evaluation of the performance on several stores. Single-channel light and current dataloggers were deployed to develop two-week, pre- and post-retrofit profiles of lighting systems. The light loggers were used to develop lighting runtimes. Each lighting circuit was measured with a true RMS handheld watt meter to correlate the runtimes to kilowatt-hrs. Data from one location indicate that the savings range from 9% to 25% of the lighting hours for a total cost savings of $700/yr for four small stockrooms. The data also indicate that adjustments to the control delay would improve the savings.

Evaluation of Demand Control Ventilation for a Retail Store. A single-channel datalogger with CO_2 sensor provided a four-day profile of sales floor zones to determine the potential for retrofit of CO_2-following ventilation control. In the four-day period studied, the CO_2 levels averaged 400 ppm with a peak of 810 ppm. A follow-up study is in progress to determine the energy penalty associated with excess outside air. This study was initiated and undertaken by the corporate energy manager.

Service Station Chain Evaluation of Energy End-Use. Using three-channel current loggers a detailed end-use of a model automobile service station revealed: (1) a high percentage of power used by miscellaneous vending equip-

Figure 7. (left) Photo of a True RMS Watt Transducer Connected at an AC Unit Disconnect. Note that the watt transducer connections are tested by reading a signal with a voltmeter prior to launching the datalogger. (right) Results of Benchmarking an AC Unit Using this Instrumentation. Note that each stage of operation can be clearly associated with a kW range.



ment (over 30%); (2) the high hours of operation on the anti-sweat heaters serving the walk-in coolers (7.5 hrs/day); (3) strong potential for occupant sensor retrofits for the restrooms. The end-use data were used to estimate cost and energy savings on a number of control and lighting retrofits including: efficient lighting (interior and exterior); photocell control of exterior lighting; humidity sensor lockout of anti-sweat heaters; and extensive use of motion sensors. A prototype station was retrofit and was shown to reduce consumption by 15% in a twelve-month period with an aggregate simple payback of less than two years. The corporation has now begun the retrofit of nearly 600 service stations. They have also incorporated these measures in the construction of new stations. The project was initiated by the customer in conjunction with their utility corporate account representative. The data collection services were provided by the EC staff.

Evaluation of a Refrigerated Warehouse. At the request of the owner, a mechanical consultant monitored operation of compressors and lights in two units of a refrigerated warehouse using single-channel current, temperature, and light dataloggers. Excessive compressor cycling was discovered (over 20 starts/hour) as well as poor staging control of the compressors. A retrofit programmable logic controller (PLC) was added to stage the compressors on load as well as provide timed switching of the lights. Savings include an estimated 100 kW reduction of demand. Commissioning of the new controller is in progress.

National Retailer's Assessment of Black Box Controller. Four-channel dataloggers with temperature, relative humidity and true RMS watt transducers were applied to assess air conditioning unit efficiencies (kW/Δenthalpy) with and without a proprietary ''energy-saving'' controller in operation. While the controller's manufacturer claimed 30%–40% savings during the two-week test period, only negligible efficiency improvements were observed. The black box controller did, however, vastly increase the number of compressor starts and stops. The study was initiated by the retailer's district operation's manager utilizing his energy management consultant. The chain was considering the use of this controller nationwide on over 300 stores.

Control of a Fabrication Facility Cooling Tower. For a four day period, cooling tower operation for a large central plant was monitored using single-channel temperature loggers immersed in the cooling tower distribution pan and basin, and hourly sling psychrometer readings. This five-cell tower serves a twelve-chiller, 17,000-ton plant. Under manual control, the tower was shown to vary between 3°F to 12°F approach wasting an estimated 2.5 GWh/yr. A major retrofit of the control system sparked by these measurements is now in progress. The study was initiated by the customer and their account representative. EC consultants performed the monitoring and simulation modeling upon which the energy savings were based.

Control of a Fabrication Facility Central Plant. A dry-well temperature bath was used to conduct an in-situ ''through system'' calibration of control sensors in an 17,000-ton, chilled-water plant. The condenser water sensor on which the tower was controlled was off by 5°F at 65°F. The sensors have now been corrected through adjustments at the programmable logic controller. The calibration utilized a scientific-grade dry-well bath that is accurate to 0.1°F with calibration traceable to NIST standards.

Study of an Industrial Plant Air Compressor. A multi-channel datalogger with current transducers served in a three-week evaluation of air compressor operation. The measurements supported the retrofit of a smaller compressor offering a 110 kW reduction in demand and 720 MWh/yr energy savings. This plant was relocated out of the state prior to any action being taken.

The preceding snapshot examples suggest the breadth of Toolkit applications. Approximately 40% of our projects have focused on HVAC systems, 40% on lighting systems, and 20% on industrial process evaluation. The next sections provide more detailed examples for the HVAC and lighting categories.

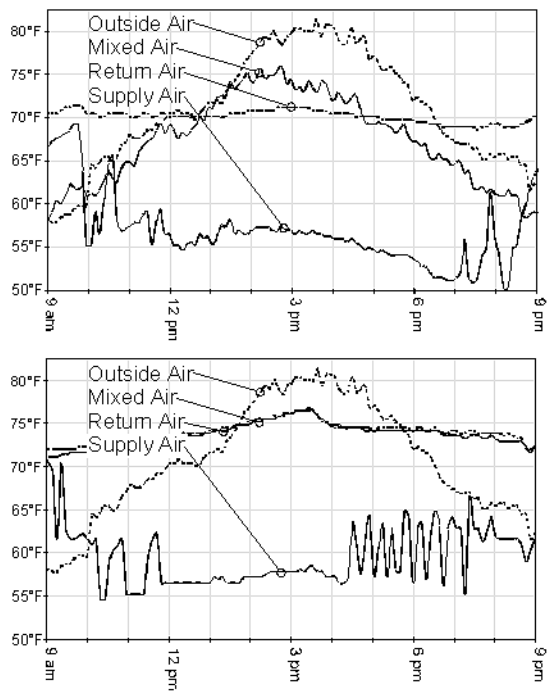
Case Study: A Retailer's Mysterious Creeping Bill

A major retailer is working on reducing the energy use in their stores with a target of 1% per year. In reviewing recent data they were surprised to find that energy consumption had increased rather than decreased. With energy efficient lighting, a fully-automated energy management system (EMS) for both lighting and HVAC, and an aggressive maintenance policy the store manager was baffled. What was causing the increase in energy use? Store hours had not changed, nor had the sales receipts (a proxy for occupant load). Management reviewed the data with their utility sales representative who in turn came to the EC Toolkit program.

A quick survey of the store's energy consuming systems revealed two possible culprits: four 60-ton rooftop air conditioning units and the time controls of the lighting circuits. Operating experience suggested that the lights indeed switched off at closing leaving the air conditioning units as the primary suspects.

A recording true RMS watt meter was used to benchmark each unit at each of its four stages of cooling. This data revealed no excessive energy usage from any of the components.

Figure 8. *(top) Data Depicting an Operational Economizer and (bottom) Data Depicting a Failed Economizer.*



The next step applied single-channel dataloggers with external temperature sensors to track supply, mixed and return air streams in each of the air conditioning units. Air temperature sensors with radiation shields were mounted near each pair of air conditioning units to track outdoor temperature. Because of the importance of these measurements and the availability of extra loggers, redundant sensors were placed at each location.

These sensors crudely but efficiently tracked operation of the air-side economizers as well as compressor cycling (through discharge air temperature) and unit runtime. In Figure 8's upper graph, mixed air tracks the outdoor air temperature whenever it is cooler than the return air. Between the hours of 1 p.m. to 5 p.m. the mixed air is slightly warmer than the return air indicating some outdoor brought in for ventilation. In the lower graph, the mixed air tracks the return air temperature at all times suggesting that the economizer dampers are fixed at 100% return air. The data clearly indicate complete failure on one of the economizers and excessive control hunting on a second (not shown). Judging from a rough bin analysis, the failed economizer wasted between 60 and 90 MWh/yr.

In addition to the economizer problems, measurements unearthed a lack of minimum ventilation air on three of the four units. Based on these short duration field studies the retailer's efforts toward energy efficiency were directed toward correcting operation of the air-handling unit.

Case Study: Lighting above the Law

A newly-constructed Federal building near San Francisco, lauded for its energy efficient design, houses Federal Courts with decidedly inefficient incandescent lights. Following judicial preference quartz projection flood lamps (150W) were employed over the courtroom's seating area and additional lamps (250W) over the bench, jury and active courtroom areas. As designed and built the courtroom had a lighting power density exceeding 5 W/ft^2 of floor space.

The energy coordinator for GSA sought EC Toolkit program assistance in evaluating the potential of retrofitting this system with 20W compact fluorescent lights with integral reflectors and ballasts. While this alternate arrangement would reduce the courtroom's lighting power density to approximately 0.8W/ft^2 it would also lower interior lighting levels. The quartz lamp design was the standard of the Federal Courts and GSA was having difficulty convincing the judges that they could have subjectively acceptable lighting with the new lamps. GSA needed qualitative data to convince court officials and others that they could use less energy with equal or improved comfort to their standard lighting design.

In addition to the excessive energy usage, a field inspection by the building operator, occupant representative, and EC staff identified a number of qualitative problems with the existing incandescent design:

Figure 9. *Fluorescent Lamps (actual replacement had an integral reflector) Replaced Incandescent PAR Lamps for a Lighting Power Reduction of over 80%.*

- Visible glare (particularly apparent on the computer screens used by the Bailiff and Judge).
- Visually disturbing bright spots on the walls.
- Thermal discomfort due to a taxed HVAC system and high radiant loads in the environment.
- Audible noise from the air distribution system as it struggled to keep up with the load.

Using a hand-held illuminance meter and an infrared pyrameter the field team evaluated surface temperatures and illuminances at the bench, bailiff's area and attorney's tables under incandescent and fluorescent sources. The tables and desks were as much as 15°F cooler under the compact fluorescent lamps. As might be expected, illuminance on the desk workplane dropped from 110 footcandles to 50 footcandles, a value still within the courtroom guidelines.

Over a year later, the ''trial retrofit'' compact fluorescent lights are still in place and the Justices are pleased with their courtrooms. Since the retrofit, there have been no complaints related to temperature control problems or audible noise from the HVAC system.

LESSONS LEARNED

After two full years of operation we believe the Toolkit program to be a novel and valued customer service. These perceptions were recently tested by surveying Toolkit users.

Telephone Survey of Toolkit Users

In February 1996, the utility conducted a telephone survey of Toolkit users to gauge their level of satisfaction with the program and to seek their advice regarding its continued development. The Toolkit database was used to generate a list of 125 candidates for interview. This list was passed to a separate utility unit where staff contacted the first 31 available subjects and posed questions in a ten-minute interview. The questions and responses are summarized in Table 2.

The survey also asked a number of open-ended questions. When asked how they learned about the Toolkit program, responses were evenly distributed across the categories of

Table 2. *Responses to a Telephone Survey of Toolkit Users (n = 31), February 1996*

Question	Average Response	Scale
How would you rate your overall experience with the Tool Lending Library?	9.19	1 (very negative) to 10 (very positive)
How would you rate your satisfaction with the equipment you borrowed?	8.87	1 (very low) to 10 (very high)
How would you rate your satisfaction with staff support of the Tool Lending Library?	9.23	1 (very low) to 10 (very high)
How would you rate the educational value of your Tool Lending Library experience(s)?	8.43	1 (very low) to 10 (very high)
Were you able to collect the data you desired?	100% yes	yes or no
Did your investigation lead to an energy-conserving action?	81% yes	yes or no
(Asked if an energy-conserving action was cited) Were you able to calculate the potential energy savings?	80% yes	yes or no
Have you gained insight into energy-efficient practice through this experience?	70% yes	yes or no
Would you recommend the Tool Lending Library to others?	100% yes	yes or no

(1) workshop at the EC, (2) heard from a colleague, (3) through a utility representative, and (4) through a publication. Regarding the specific energy-conserving actions taken, the majority of respondents cited retrofits of HVAC and lighting components. The other large category of actions involved the tuning and maintenance of control systems. A final question asked where respondents would direct future funding of the Toolkit program. The most frequent responses were more equipment (60%) and more classes (35%) with suggestions for increased marketing running third.

It is our observation that the Energy Center's provision of support services (e.g.; technical staff, training programs, application notes) is a necessary ingredient for this type of program.

The utility's Toolkit effort is still young. During the upcoming years the utility will add to the program's collection of equipment, workshop offerings, devices, and procedures. In the spirit of Harry Tuttle we will continue to learn about the performance of contemporary building systems and initiate remedies where possible. The experience gained will also provide useful feedback for programs advising those involved in new construction.

ACKNOWLEDGMENTS

We continue to learn at a steady pace from the interesting building diagnostic problems presented by the Toolkit's customers and thank them for this experience. Brad Gustafson, a former EC staff member now with Lawrence Berkeley National Laboratory, participated in the development of the Toolkit concept and was its first manager. Nyle Brandenburg, then a student at San Jose State University, contributed to early equipment evaluations. Bill Burke and Alison Kwok, both with the Vital Signs Project, have been among the most active testers of the Toolkit's devices and have contributed to the development of instructional materials. Ryan Stroupe has just joined the Toolkit program and manages its day to day activities. The Toolkit is described in detail at the EC's World Wide Web site. You can find a listing of devices, images of individual instruments, and details regarding equipment vendors at
<*http://www.pge.com/pec/tooltoc/toollib.htm*>.

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