# Free Cooling: At What Cost?

*Kristin Heinemeier, University of California, Davis*

## ABSTRACT

Air-side Economizers provide "free cooling" for commercial-building Rooftop Units (RTUs) when the air outside has an appropriate temperature or enthalpy. They can provide on the order of 20-30% cooling energy savings, in California climates.

This paper discusses the prevalence and causes of failures in economizers. The author conducted a survey of California contractors and found that 30-40% of the time, the economizer is disabled and the outside air dampers are closed. This type of failure means that the economizer is not providing any savings, and that the building may not be bringing in any outside air. Other studies have found that the high-limit setpoints, set by technicians, are incorrect on the majority of RTUs in California, resulting in very few hours in the "free cooling" range. The author has calculated the energy penalty of having the wrong high-limit setpoint.

Economizers are required in many building codes, nationally. California's Title 24 energy code requires economizers, and also specifies the types of economizer control that are allowable. In an innovative mandatory measure, economizers are required to have Fault Detection and Diagnostics (FDD) capabilities. In addition to these measures, there is factory certification required in some instances, along with field acceptance tests.

This paper describes the problems and solutions with existing economizers in the field, from a behavioral as well as a technical perspective. It describes the challenges and opportunities for potential utility-funded rebate programs that target repair, replacement, and decommissioning.

## Introduction

Air-side economizers provide "free cooling" for commercial-building RTUs when the air outside has an appropriate temperature or enthalpy.[1] They can provide on the order of 20-30% cooling energy savings in California climates, and can provide significant savings in most US climates.

An economizer is comprised of several components, including an outside air intake that is large enough to bring in 100% outside air, an exhaust air exit which may or may not include a relief fan, a damper assembly that interlocks the outside air dampers with the return air dampers to bring in variable amounts of outside air, outdoor air sensors (can be dry-bulb temperature or enthalpy), optionally a return air sensor (can be dry-bulb temperature or enthalpy), and a controller.

The controller takes input from the sensors in the outdoor air (temperature or enthalpy) and determines whether the outdoor air is suitable for introduction into the building. There are different types of economizer control. For a single-ended (changeover) economizer, it compares the outdoor air (temperature or enthalpy) with a high limit setpoint, and for a "differential" economizer it compares outdoor air conditions with the return air conditions. The high limit

[1] Enthalpy is a combined measure of energy that includes both temperature and humidity

setpoint is the setting, temperature or enthalpy, above which the economizer determines that the air is now inappropriate to bring into the building, and the outdoor damper starts to close.

Figure 1 illustrates the conditions in which an economizer cycle can or cannot provide benefit. It shows the hourly incidences of temperature and humidity in the Sacramento climate zone in one year. If the temperature is too hot or too cold, or the enthalpy indicates too much humidity, outdoor air should not be introduced to the building. Different climates have different numbers of hours in the "free-cooling range," so the potential from savings varies substantially for different climates, and for different high limit setpoints. Sacramento, clearly, has many hours in the free-cooling range, and is quite suitable for economizer operation.

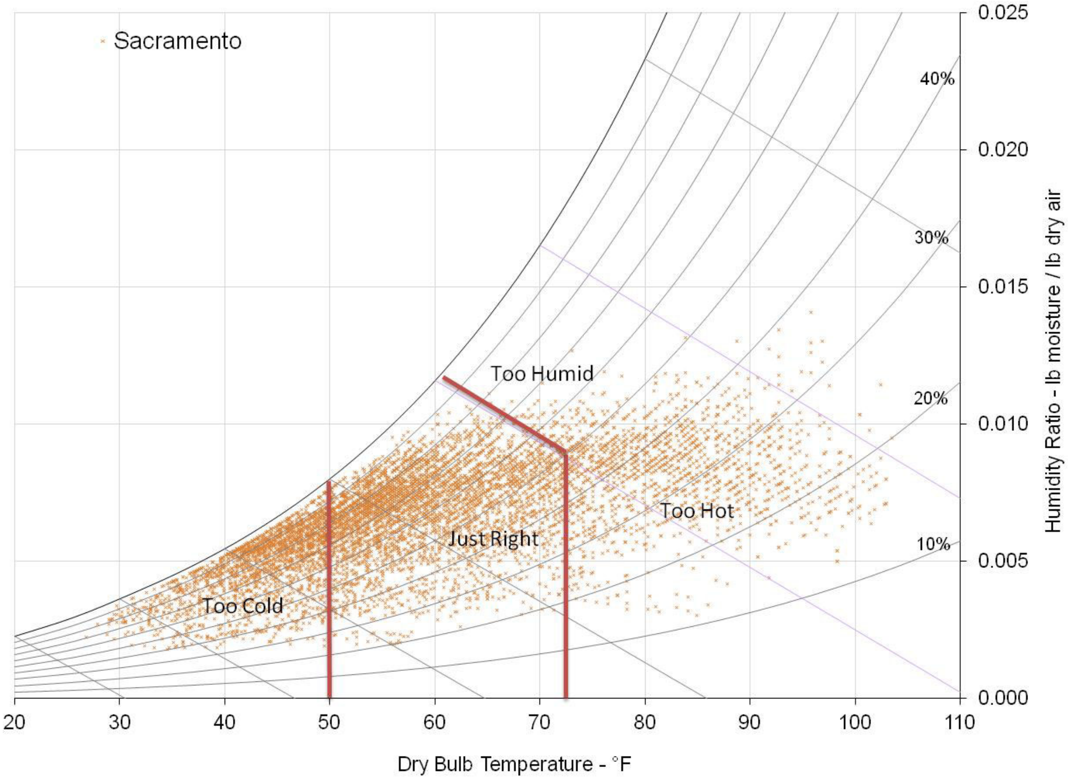


Figure 1. Climate conditions that are conducive and not-conducive to economizer savings.

## Requirements in Codes

Economizers are required in many building codes, nationally, and internationally. For example, ASHRAE Standard 90.1 (ASHRAE 2010) and the International Energy Conservation Code (ICC 2012), both of which are adopted by many states as the basis for the local building code, require economizers installed on any rooftop unit that is larger than54,000 Btu/h in some climate zones. Economizers have also been required by California's Title 24 for some time. Every three years, Title 24 is revised to increase energy savings, ratcheting up to a requirement for Zero Net Energy commercial buildings by 2030. The changes made to Title 24 for 2013 (CEC, 2011) included:

- Fault Detection and Diagnostics (FDD) was previously included as a compliance option, and was added for 2013 as a mandatory measure.

- A thermostat with two stages of cooling was added for single zone systems whenever an outside air economizer is present. This allows for integrated economizer operation, increasing energy savings.
- The prescriptive baseline for economizers was lowered from 75,000 Btu/h to 54,000 Btu/h.
- The statewide maximum allowed damper leakage was reduced to 10 cfm/sf at 1.0 in w.g.
- The high limit switch requirements were modified. The high limit setpoint requirements have been changed from the previous version of Title 24, for different types of high-limit control. Note that "electronic enthalpy," "differential enthalpy," and "dew-point and dry-bulb temperature" control are no longer allowed in California, while "Fixed Enthalpy + Fixed Drybulb" were added.

The new mandatory requirement for economizer FDD should result in improved economizer performance statewide. Any economizer on an RTU over 54,000 Btu/h is required to be able to detect a number of common economizer faults. In addition, the fault anunciation must be transmitted off the roof, the FDD algorithm must be factory certified based upon laboratory tests, and the field installation must be verified by the contractor using defined field acceptance tests.

The detailed requirements for lab certification tests have not been formally defined. The potential for widely ranging methods and sensitivities can lead to confusion in the marketplace. Because of the need for standardization in the industry, ASHRAE has convened a committee to draft a Standard Method of Test for RTU FDD (SPC 207P). It is expected that this standard will be released for public review in 2015. Note that it is not the job of this standard to determine how accurate an FDD tool should be, but rather to provide a standard test method—a meter-stick—against which to measure an FDD tool (just as an ASHRAE method of test typically defines the test methods, and a separate AHRI standard sets the test conditions, and both are used for code adoption). It is left to building codes (such as Title 24) and other policies and programs to determine what fault intensity or fault impact should be detected.

## Challenges to Economizer Operation

Although economizers are an excellent energy saving technology, in practice, out in the field, they are not performing well. Many different studies have identified the rates at which economizers, in new and existing RTUs, tend to fail. Table 1 shows the failure rates identified by different researchers, in different scenarios.

Table 1. Economizer failure rates found in various studies

| % Failure | Source | Notes |
|---|---|---|
| 43% | AEC 2002. | Just damper faults. |
| 50% | Mike Kaplan, Personal Communication with Dave Sellers, 1999. | New construction. |
| 56% | HEC, 1993. | Economizers up to two years old. |
| 64% | Jacobs and Higgins, 2003; and Jacobs et al., 2004. | 124 RTUs 10 tons or less, with economizers. |

| | | |
|---|---|---|
| 64% | Jonathan Woolley, Personal Communication, 2013. | 22 RTUs with economizers. |
| 65% | Goody et al. 2003. | Small commercial RTUs. |
| 66% | NEES, 1993. | Units two years old or newer |
| 70% | Davis et al. 2002. | Small number of RTUs. |
| 70% | KEMA, 2013a | Economizers that had been fixed up to a year ago. |
| 75% | Craig Hofferber, Personal Communication with Dave Sellers, 2000. | Estimate from interviews with consultants, mechanical contractors, and commissioning agents. |
| 80% | Felts and Bailey, 2000. | Existing RTUs |
| 100% | Pratt et al., 2000. | Four of four RTUs investigated. |

Failure modes in Jacobs' field study included dampers that were stuck or inoperable (38%), sensor or control failure (46%), or poor operation (16%). The average energy impact of inoperable economizers was about 37% of the annual cooling energy. Other than this study, there is not much documentation of what the specific failures are. To find out what some of the specific faults are, the author conducted a survey of about 20 California commercial building contractors, and found that economizer faults are perceived to be quite common. Table 2 shows the results when contractors were asked "What percent of existing commercial RTUs have the following faults?" The survey found that 30-40% of the time, contractors find that the economizer is disabled and the outside air dampers are closed. This type of failure means that the economizer is not providing any savings, and that the building may not be bringing in any outside air.

Table 2. Results of contractor survey on the prevalence of various economizer faults

| | |
|---|---|
| Economizer is disabled and dampers are closed | 30-40% |
| Actuator/linkage broken, misaligned, or loose, due to normal wear and tear or lack of lubrication | 20-30% |
| High/low limit setpoints incorrect, set by installing contractor | |
| Range/action setup incorrectly | |
| Min Outside Air is not set correctly: too low | |
| Actuator/linkage broken, misaligned, or loose, due to occupant/operation staff action | 10-20% |
| Min Outside Air is not set correctly: too high | |
| High/low limit setpoints incorrect, set by factory | |
| Dampers mechanically forced open | |
| OA Sensor (db, enthalpy) malfunction | |
| OA Sensor (db, enthalpy) drift | |
| High/low limit setpoints incorrect, set by occupants/operating staff | 5-10% |
| OA sensor (db, enthalpy) miscalibration | |

These economizer failures have either energy penalties or indoor air quality penalties. For example, when the damper and actuator linkages break or are disconnected, most economizers revert to the fully-closed position, resulting in insufficient ventilation air and poor indoor air quality. In this case, fixing the economizer may actually increase energy consumption, but it is necessary since adequate ventilation is a requirement.

In general, the magnitude of savings from an economizer depends directly on the high limit setpoint. Some economizers use a dial setting of "A," "B," "C," or "D", representing a set of enthalpy curves (the "A" setting results in the most hours of economizer cooling, and "D" the fewest). However, in Jacobs' field study, it was found that the high limit setpoints were set incorrectly in most cases. "A" was used only 28% of the time and either the "C" or "D" setting was used 60% of the time. Figure 2 shows the potential for savings in a number of different California climate zones as a function of the high-limit setpoint. Clearly there are significant savings associated with setting the setpoint correctly, while a lot of those savings are not realized when the setpoint is not set correctly. However, contractors typically either are not aware of the optimal setpoint, they leave the economizer at the default setpoint, or they adjust it over time to alleviate comfort complaints.

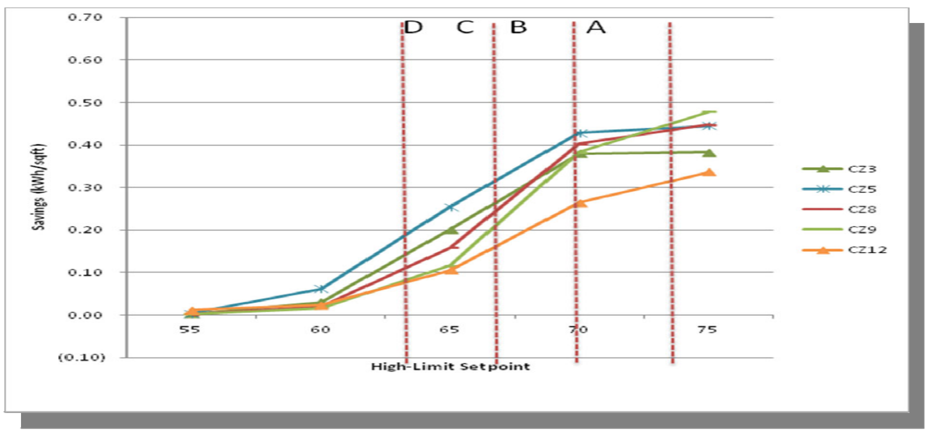


Figure 2. Economizer savings in different California climate zones, as a function of high-limit setpoint.

Aside from losing this opportunity for savings, however, broken economizers can actually *waste* energy, and in some cases, wasted energy can be ten times as high as potential savings (Lunneberg 1999). Economizers that fail in the fully open position contribute to extremely high peak loads, because more heating and cooling energy is needed to condition the excess air the economizer lets in. For example, in a simulated building in Bakersfield, an economizer stuck in the fully open position would add 84% to the summer peak load (EDR 2011). In another example, in this case a real building, an economizer in a Texas building was stuck open, causing the economizer to take in too much outside air during cold weather, and costing the facility about $2,000 a year in additional energy (Liu et al. 1994). It was subsequently disabled during the winter, and once the economizer was locked in place, steam consumption dropped dramatically. Costs involved with field repairing economizers have caused some researchers to recommend disabling rather than fixing broken economizers under some conditions. See Felts (2000) and Lunneberg (1999). A malfunctioning economizer can be worse than no economizer at all. It is for this reason that "decommissioning" a faulty economizer may be a valid energy savings measure, when repair or replacement are not viable options.

## Recommendations

Theoretically, the presence of an economizer cycle has the potential to be an excellent energy savings measure in many climates, and should be promoted. In reality, however, the poor condition of existing economizers suggests that that potential is not realized, and in some cases they may be doing more harm than good. Should installation of economizers be discontinued? Probably not. By understanding the problems with economizers technically and behaviorally, perhaps we can improve the practice of installing and maintaining economizers and help them to reach their potential. This section describes some improvements that would help to promote this.

**Improve economizer design or specification.** More appropriate design of economizers and their controllers can help to alleviate some of the problems that have been found in the field. Several years ago, a panel of experts developed the specification for an "Advanced RTU." They provided recommended economizer design features at several levels (AEC 2008). Several of these features have now been incorporated in building codes, such as Title 24, and others should be considered. These improvements can be made by specifiers or equipment designer engineers and promoted through building codes, equipment efficiency standards (potentially), and utility incentive programs.

Another program which proposed improved economizer features was the "Western Premium Economizer Control," first proposed by the Eugene Water and Electric Board (Hart et al. 2006). This specification is characterized by features such as barometric relief dampers, two stage cooling, differential dry-bulb changeover, integrated operation, and setting minimum outdoor air using measured temperatures to calculate outside air fraction.

Several manufacturers have recently introduced Advanced Digital Economizer Controllers (ADECs) designed to provide some of these features.

**Conduct quality installation and commissioning**. Because many economizers are not working from the first day they are installed, the proper installation and commissioning of this sophisticated control are essential. The technicians are always encouraged to follow manufacturers' instructions for installation of the mechanical components and the controller and sensors, as well as configuration for the details of the application. These instructions provided by manufacturers should be reviewed for adequacy. It may be that there is a role for an industry-wide installation guideline (much more detailed and targeted than the ACCA Quality Installation guidelines).

Throughout the installation, the technician should observe, inspect, and test the various components of the economizer: Does the economizer actuator work? Do the dampers move freely over their full range (fully open to fully closed)? Are mixed-air sensors correctly installed across the flow area? Is the minimum outdoor air damper setting correct? Are the sensors calibrated? Are the high-limit temperature setpoints set appropriately for the climate? Is the operation proper and capacity of exhaust/relief mechanisms adequate with all doors, windows and other openings closed?

Acceptance tests, in the form of Functional Performance Tests (FPTs), should be carried out to simulate conditions under which the economizer should operate and confirm that the operation sequences are correct and the unit responds correctly when subjected to conditions where the economizer should operate. There are many sources of FPT specifications for economizers, including example diagnostic plots for identifying mis-installation or mis-configuration problems (Jacobs et al. 2004), and detailed commissioning test specifications in

Energy Design Resources (EDR 2011), and the Functional Test Guide, (PECI 2008), and initial check-out recommendations (CEE 2001).

ADECs make use of more accurate and reliable sensors and solid state digital controls to provide sophisticated ventilation cycles such as demand-controlled ventilation and variable speed ventilation. This added complexity could be difficult to support in the field installation and configuration, however they also provide a "commissioning" mode, in which the technician can more easily step the controller through all of its modes of operation, and confirm that it is installed and configured correctly for the application and climate. In addition, the ADECs include automated Fault Detection and Diagnostics (FDD), which can identify inappropriate installation and configuration, as well as identify problems that emerge over time.

**Conduct quality maintenance, including energy-focused checkout of economizer.** Whether the economizer was installed correctly or not, it will need to be revisited over time, through a quality maintenance protocol, or an energy-focused checkout of the economizer.

Since routine preventive maintenance generally involves only filter changes, coil "inspection," blower lubrication, and a cursory check of unit operation (PECI, 2002), it is important that a more rigorous maintenance plan be developed for economizers. ASHRAE, ACCA, and ANSI have developed a standard for quality maintenance practices for inspection and maintenance of commercial building HVAC systems (ASHRAE, 2011). "Standard 180" covers the full range of commercial equipment, and has a specific "check-list" of required maintenance and inspection tasks for RTUs and economizers, along with a recommended frequency.

In addition to these detailed technical tasks, the standard provides the outline of a "Maintenance Plan," including performance objectives, condition indicators, documentation requirements such as: a listing of systems and components with associated performance criteria pertinent to the facility, the method of tracking inspection and maintenance tasks (automated or manual), sufficient record detail and verification (written or electronic) to demonstrate implementation of the maintenance plan, and emergency information.

Experts are still divided on how often maintenance beyond Standard 180 should be provided. While a thorough energy-focused check-out is critical upon initial installation or upon initiating a service contract, it would probably not be cost effective to provide this level of rigor on a too-frequent basis for every economizer. Some researchers have proposed definition of a two-tier program structure, wherein a "standard" effort (corresponding with implementation of Standard 180) will be applied periodically to units or entire sites where data either does not indicate faults or they are prioritized to be at lower risk of having performance problems, and a "premium" effort (going beyond Standard 180) will be applied to the remaining units, especially those with specific identified faults (Todd Rossi, Personal Communication, 2014).

The resources described above for commissioning of newly installed economizers also provide guidance on ongoing performance tracking and detection of faults and maintenance requirements.

**Continue to pursue utility programs.** The California Utilities have recognized the importance of economizers and of the need to pay special attention to ongoing performance issues. They are currently fielding several incentive programs that affect economizer performance. Utility programs can have the impact of leading the industry's development of technologies and practices that dramatically improve the performance of economizer.

The "Air Care Plus" program provides an energy-focused "tuneup" of an RTU, including special focus on the economizer (Air Care Plus, 2014). In addition, Southern California Edison's "HVAC Optimization" program (commercial quality maintenance) has recently added new incentives for the installation and maintenance of economizer controls on program-enrolled HVAC units (SCE 2014). The intent of the new incentives is to give contractors and their customers another opportunity to implement quality HVAC maintenance that is consistent with ASHRAE's Standard 180 recommendations. These new possible measures include adding a new economizer or repairing, replacing, or decommissioning an existing economizer. The new or replacement economizer controller can either be a standard model, or an ADEC. Other measures include replacing the damper assembly and replacing the damper motor. The other California utilities have similar programs.

The training requirements for diagnosing, repairing, replacing, or decommissioning existing economizers in the California utilities' programs include meeting all standard program qualifications, completing an ADEC qualification questionnaire, taking an online economizer assessment, and completing a 2-3 hour hands-on exam. Once these steps have been taken, the technician is qualified to provide economizer services within the program. They can also pursue additional training to receive a "master-level economizer certification." The adequacy of these trainings and certifications should be studied, and any necessary mid-course corrections should be made to maximize savings in these programs. This type of intensive technical training is essential to the proper operation of economizers.

Historically, the evaluations of savings from quality maintenance programs have had disappointing results. In the evaluation of the California utilities' Refrigerant Charge and Airflow programs from 2006-2009 (KEMA, 2010), realization rates and net-to-gross ratios dramatically reduced the allowed savings. An interim evaluation of the 2013-2014 programs found several concerning procedural factors that are calling the program savings into question (KEMA 2013a). They concluded "the programs should be redesigned to provide more effective energy-efficiency measures, training, tools, protocols, and data collection." Since this was an early interim report, the CPUC and the utilities now have the opportunity to respond to these concerns and improve their programs to maximize savings.

**Conduct research to understand behavioral issues.** While there is little research into what the specific failures are in the field, there is *no* research into what causes these failures or what practices or attitudes allow them to stay broken. Why are economizers so prone to failure? Although their basic principle of operation is simple, in practice they are quite complex, and most technicians do not understand all the complexities of how they work. Human factors have a big influence on the performance of economizers.

In some cases, the failures exist from the moment the economizer was installed (one contractor reported investigating the performance of an economizer, and discovering that the economizer was still in the packing position, meaning the installer never completely installed it or never ran power to it). In some cases, the economizer is intentionally "temporarily" disabled, to address another pressing issue with the system. For example:

- A unit that is undersized and having difficulty meeting load during extreme heat and cold, leading to comfort complaints; hence a decision to keep the dampers closed.
- A customer that doesn't want to pay for something that doesn't affect comfort, so they won't pay to fix the economizer.

- Equipment that is in the vicinity of a lot of wood stoves/fireplaces during winter, causing indoor air quality issues in the space.
- During morning warm-up on gaspacks you may get complaints of a gas smell from the tenant.
- RTU's are installed over grocery departments in the summer, when humidity is high.
- Bringing in undesirable outside odors, often truck fumes from units near loading docks.
- The fresh air intake is installed directly over a vent stack.
- Two units installed side by side and the gas exhaust of one is directed towards the economizer of the other.

The cost of repairing or replacing is often quite high, and "temporary" can become “permanent” quite easily. Units generally are serviced only when they stop delivering cooling (Jacobs et al 2004), so any of a number of faults can appear and can be present for years before someone looking for energy savings opportunities looks carefully at the economizer.

To better understand the human factors that influence the outcome of installation and maintenance services, the author conducted a study of residential maintenance contractors (Heinemeier and Barriga, In Press; and Steiner et al. 2012). Technicians were called to perform maintenance on a residential air conditioner, and researchers, in the guise of homeowners, observed them from technical and behavioral points of view. Through this study, we determined that technicians did not take many measurements, and when they did, they did not write them down, or use them to discuss potential fixes with the homeowners. Technicians did not feel it was their role to promote energy efficiency, and in some cases, actually discouraged it. They did not seem to go out of their way to portray themselves as sophisticated professionals, providing a competent service that would provide a unique benefit to their customers. Our conclusion from this study was that technicians are allowed too little time to do a thourough job. Spending more time on the job would, of course, require a higher fee, which most customers would not be willing to pay. We concluded that a new type of more technically sophisticated services is needed, along with documentation of services provided and value of the improvement. This is the type of industry evolution that will result in more functional economizers in the field.

More research should be done into behavioral factors and their influences on economizer performance. HVAC technicians and contractors are hesitant to sell Quality Maintenance (QM) services because they do not have the tools to convince customers (and themselves) of the value of QM, and they are averse to risking their customers’ trust (Barriga et al. 2012; Heinemeier et al, in press and EMI 2012). Contractors are thus less than fully effective at selling QM services and service contracts. Technicians need training in which their role as “expert communicators” is emphasized. It is possible that by providing technicians with a tool to show value to customers, in the form of a report of maintenance measurements, interventions, and recommendations, can be effective in encouraging technicians to promote QM more energetically, increase customer commitment to QM and willingness to pay, and increase technicians’ confidence in their ability to act as qualified and effective energy efficiency communicators.

## Conclusions

Economizers are a difficult technology to promote in the market. Despite the promise of up to 30% energy savings on cooling, they usually don’t operate as designed, and they’re often too complicated for the people typically installing and repairing them. They are not “cool” and they are essentially invisible. Customers are not aware enough of the benefits of a functioning economizer or the costs of a malfunctioning economizer, and are typically unwilling to invest in making repairs (despite the favorable life-cycle cost). Given their potential, however, it is worth more closely identifying and solving some of their field problems.

This paper described some of the benefits of economizers, as well as the challenges to their performance in the field. It described the research on failure rates in the field (averaging about 60%), and the consequences of various types of failures. There clearly is not enough known, however, on exactly what is going wrong with economizers, and what are the root causes of these failures. This paper provided several recommendations on areas where improvements can be made, both in the performance of economizers, and in our understanding of the role of human factors in that performance:

- Improve economizer design or specification
- Conduct quality installation and commissioning
- Conduct quality maintenance, including energy-focused checkout of economizer
- Continue to pursue utility programs
- Conduct research to understand behavioral issues

Persistent energy savings will only result if all stakeholders “buy in” to the requirements of this temperamental-yet-effective system. Improvements in the future may include both smart self-diagnosing transducers and controllers, as well as smarter, more creative technicians with sufficient training, adequate tools, and an appropriate temperament for diagnosing complex pieces of equipment (it has been described as a “forensic personality”). What are also needed are tools to help technicians describe the value of an appropriately functioning economizer to a potential customer, and motivations for contractors to try and make this case. There is an important place for intelligent hardware, but the human element is always going to be there, and researching the behavior of actors in this market will help identify ways to make this important technology deliver on its promises.

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