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Technology Installation Review

A case study on
energy-efficient
technologies
prepared by the
New Technology
Demonstration Program

Energy Savings in Refrigerated Walk-in Boxes

Results of an assessment of a technique for saving energy in refrigerated walk-in coolers

Introduction and Background

The purpose of this Technology Installation Review is to provide an overview of the results of an assessment of a technique for saving energy in refrigerated walk-in coolers, and to evaluate the potential for this technology in Federal facilities. The focus of this study was on a single manufacturer of the technology, Nevada Energy Control Systems, Inc. (Necsi); no other vendors for this technology could be found.

Previous studies were inconclusive about the overall efficacy of this technique due to uncertainties in a number of areas.[1] Previous evaluations also lacked the benefit of the results from recent manufacturer sponsored tests and did not address some fundamental issues about the overall efficacy of this technology that are critical to understanding its potential. The primary objective of this assessment was to determine if the previous studies combined with recent vendor sponsored test results substantiate the manufacturer's claims that this is a cost effective energy saving technique with significant potential in Federal facilities. Secondary objectives included evaluation of intangible benefits such as equipment life and reliability issues, and humidity and airflow effects on product.

Technology Description

Walk-in boxes are used in a wide variety of applications but their use in food sales and service facilities dominates all other uses (see market size discussion below). There are two major classes of walk-ins: low temperature (-10 to -20°F) and medium temperature (-10 to 30°F). In most cases the panels, refrigeration components and controls are ordered separately and assembled on site by local refrigeration contractors. Some smaller units are supplied fully assembled. Sizes are typically 80 to 750 sf and 8 to 10 ft high; or about 640 cu ft to 7500 cu ft; the average size appears to be in the range of 2000 cu ft. Condensing units are split systems with semi-hermetic compressors rated at 1.5 to 5 hp and operate with HCFC-22 or HFC-404A refrigerants.[2]

The typical target application of the Necsi control is a medium-temperature, medium-to-large cooler with a dedicated (or rack) refrigeration system that operates with single-phase powered evaporator fans. The control is not intended for freezers since most freezers use electric defrost and cycle evaporator fans off during the compressor off-cycle. These systems also tend to have longer run times and less load variation than coolers, which limits their energy savings potential.

Principles of Operation

The design and operation of the control are very simple. An auto-transformer is installed in the evaporator motor electric power circuit. This auto-transformer supplies low voltage to the motors (typically one or more banks of 1/20-hp motors) whenever there is no call for cooling; i.e., when the compressor is off in dedicated compressor systems or when the liquid line solenoid is closed in a rack system. The switch to low voltage is caused by a logic circuit that senses the decrease in temperature difference across the expansion device using two thermistors. Control, therefore, is not directly tied to compressor operation, only to sensing of flow via temperature sensors. This allows the technique to be also used on rack systems where a solenoid valve in the liquid line cycles each unit cooler on and off for space temperature control. At low voltage (approximately 35% of primary voltage) the motor operates at reduced speed (typically ~400 rpm) and airflow. Power input (including the effect of auto-transformer losses) is reduced by about 75-85% when operated at low speed.

This speed control technique is limited to single-phase shaded pole and permanent split capacitor motors. The controller is supplied in two models rated at 10 amp, 110/115 vac and 5 amp, 208/220 vac, respectively.

Potential of Applications

Limitations

The preferred application for these controls are medium-sized, medium-temperature (28-40° F) walk-in coolers with shaded pole evaporator fan motors and where the refrigeration system has been oversized with respect to actual loads. Although this technology is applicable to installations with permanent split capacitor motors, the savings magnitudes will be greater with shaded pole motors due to their lower overall efficiency. The magnitude of savings must be carefully calculated for each specific site with the major parameters fully accounted for until better estimating methodologies are developed. Assumptions based on previous test results from other sites should not be generalized to a candidate site.

Federal Sector Potential

Applications of this technology in Federal facilities are subject to the same limitations and caveats that apply to private sector facilities. There are an estimated 129,000 walk-ins (coolers and freezers) combined in Federal, state, and local government buildings. Since Federal facilities make up only 13% of the total number of government buildings, there are an estimated 12,000 walk-in-coolers in Federal facilities that are potential candidates for this technology.[1,2] The estimated maximum savings (if all potential applications were retrofitted) using conservative estimates of percentage savings is about 155,000 Mbtu/yr. The actual potential is somewhat less than this since many walk-ins will not be practical candidates for this technology, and it is not known how typical Federal facilities are compared to all other government facilities.

Cost Effectiveness

Since cost effectiveness is driven by the magnitude of savings and its cost relative to cost of implementation, savings percentages per se are not good indicators of the efficacy of this technique. A detailed estimate of cost effectiveness was beyond the scope of this study, but it is clear that this computation is much more complex than it appears from the manufacturer's perspective. Although implementation costs are well established at $400 to $500 per controller plus $100 for installation, the magnitude of savings is highly site specific. In addition, for the reasons stated below, the methodology used to estimate annual energy savings may be inaccurate. Based on results of a single test, these savings could be understated or overstated depending on the specific operational and system design aspects of a particular site.

Using percentages demonstrated by the test results can be misleading if they are applied to historical energy use based on billing meter data. Because these results reflect the sum of condensing unit and evaporator energy only and not the entire walk-in box installation, existing energy use must be disaggregatated to separate out compressor and fan energy before percentages are applied.

Overall, the cost effectiveness based on test results and analyses to date cannot be generalized. Lacking a well-developed energy savings estimation methodology that accounts for all major factors that affect performance, each situation has to be considered on its own merits. These calculations should include consideration of all of the major factors identified in this report.

Summary and Conclusions

This review produced mixed results in terms of verifying the expected savings magnitudes and cost effectiveness of using this technique in Federal facilities. On the positive side are these issues:

1. The technology is simple, direct, and relatively inexpensive to apply.
2. The technology does save energy both directly by reducing evaporator fan energy and indirectly via reduction of compressor energy due to reduced heat gain from the fan motors. The overall potential of this technology is enhanced by the fact that about

75% of all walk-in boxes use low-efficiency shaded pole motors.

3. The energy savings measurement methodology, although not ideal because power factors are assumed to be unity, appears to be substantially correct for permanent split capacitor evaporator and compressor motors and reasonably reflects savings in active power under the test conditions encountered. This is not the case, however, for shaded pole motors (see below). In addition, by ignoring the effect of change in power factor from full speed to low speed, savings for shaded pole motors are underestimated by about 5%.
4. Stratification due to low speed evaporator fan operation does not appear to be a significant problem.
5. The total savings potential for Federal facilities appears to be greater than previous estimates even for low estimates of savings. The estimated number of walk-ins (coolers and freezers combined) in Federal facilities to which this technology is applicable is about 12,000.

On the other hand, the following issues should be taken into account when this technology is being considered for use:

1. The percentage and magnitude of savings (and therefore cost effectiveness) are highly variable and dependent on specific site conditions. The energy savings potential for a particular site cannot be generalized to other sites from any of the information available without further analysis and/or testing. Three major factors affect the magnitude of savings at a particular site:

- Temperature dependence—extrapolation of results from a single test to annual performance cannot be assumed to be accurate without a more complete understanding of the system performance variation with ambient temperature. Performance can be affected by the head pressure control strategy used for the condensing unit, dependence of cooler load on outside weather, and the weather patterns at a site.
- Oversizing—system design capacity relative to actual loads (condensing unit and unit cooler) has a major impact on savings since it directly affects the time that the evaporator fans operate at low speed. Oversizing can vary appreciably between sites.
- Motor type—the motor efficiency for shaded pole motors (~35%) is significantly less than that of permanent split capacitor motors (~50%-65%). The magnitude of savings will vary depending on the type of motor used. Efficiency at reduced speed, although extremely low (~4-5%), is about the same for both motors.

2. Power factor was not used in computing the savings for any of the sites except for one test where a wattmeter was used. Since the power factor for shaded pole motors is about 60% or less, the savings magnitudes are significantly overestimated for the sites with these motors.
3. Although not necessarily germane to the technical assessment focus of this report, there is a large discrepancy between Bureau of Census data used by Necsi and that based on Commercial Buildings Energy Consumption Survey (CBECS) data[3]; thus the market size claimed by the manufacturer could be significantly overstated. Based on recent CBECS data there are a total of approximately 700,000 walk-in boxes to which this technology is applicable. As stated above, however, CBECS data also show that the potential in the Federal sector computed by the New Technology Demonstration Program appears to be underestimated.
4. Intangible benefits such as improvement in relative humidity, reduced space temperature, and increases in compressor and fan motor longevity, although important in some applications, in general appear to be of limited impact. The selection of this technique should not be made based solely on these intangibles. However, there is no indication that these effects negatively impact the use of this technology. Reduced desiccation due to reduced air velocities over open organic products does appear to be of significant benefit, although the magnitude of this effect has not been substantiated.
5. Based on motor manufacturers input, the bearing life for evaporator motors when operated below 500 rpm is of some concern. However, because of the way that these motors are operated with the Necsi control, motor problems do not appear to be significant.
6. Some care should be exercised when interpreting percentage savings claims. The savings shown by Nesci are the combined compressor and evaporator fan energy savings only; these typically account for about 90% of total energy consumption of a walk-in box but will depend on which loads are included on the meter used to measure walk-in box energy use.

Appendix A: Performance Assessment

This section contains amplifying details that may be important to the interested reader.

Test Results

As shown in Table 1, the results from these tests are highly variable in both percentage and magnitude of savings. The results are skewed by the fact that power factor was not included in the calculated savings for the evaporator fans for all but one test (test E). These results underscore the difficulty in predicting savings and generalizing results from one site to another. There is no clear correlation between tests other than the fact that some savings are shown for all sites. The variation and lack of correlation in these results is not surprising given that the tests were conducted in installations and under operating conditions significantly different from one another. The tests span a wide range of box sizes, load ratios, evaporator motor types, and weather conditions.

Motor performance

There are two types of electric motors that are used for walk-in coolers: shaded pole and permanent split capacitor. These are four-pole, direct-drive motors typically rated at 1/10 to 1/20 hp. According to manufacturers, about 75% of unit cooler production is shipped with shaded pole motors.

The lack of true power measurements on the evaporator motors has resulted in considerable confusion in interpretation of the results. In the field tests, power input and savings were computed from measurements of voltage and current to calculate VA—(Volt-ampere—apparent power) as opposed to measuring wattage (active power) with a watt meter or

Table 1. Summary Results of Vendor-Sponsored Tests (vendor data [4])

Test	Purpose	Location	Test Date	Box Located	Ambient Temp Range (Daily average)	Cooler size, cu ft	Compressor duty cycle before/after, %	Motor type	Avg. Daily Energy Savings, %	Energy Savings, Avg. daily KWh	Energy cost savings, $/yr[a]
A[b]	Food service	Stockton, CA	Feb-Mar 1997	Inside	40-548° F	865	21/13	permanent split capacitor	44	6.0	175
B	Food sales	Fremont, CA	Feb-Mar 1997	Inside	55-67° F	5695	31/31	permanent split capacitor	15	7.4	229
C	Food service	Walnut Creek, CA	Mar 1997	Outside	58-68° F	2739	16/12	shaded pole	59	8.8	569
D[c]	Food service	Sacramento, CA	Jul-Aug 1997	Inside	64-107° F	2287	69/65	shaded pole	13	19.2	657
E[d]	Food sales	Sacramento, CA	Aug-Sep 1993	Outside	70-83° F	2500	38/33	shaded pole	24	9	400

(a) These are energy savings only, equipment and maintenance savings are not included.

(b) This test did not include condenser fan energy in compressor energy measurements since condensers were common with other refrigeration units.

(c) Compressor was not dedicated; a display case was supported. Therefore, the magnitude of compressor savings that should be credited to Nesci control is not known. No outside temperatures measured.

(c) A watt meter was used for this test.

watt transducer (except for test E). Power savings will only be accurate using this method if the power factor is close to unity and is constant between full and low speed. Computer simulated performance curves for shaded pole and permanent split capacitor motors operating at full and reduced voltage were obtained from Fasco.[5] A performance curve for a typical 10-inch fan was overlaid on these curves to identify the operating point for these motors. These curves accurately reflect field experience and testing conducted by Nesci; i.e., motor speed at 40 Volt AC input is about 400 rpm. These tests do not, however, show the effect of using an auto-transformer to operate the motor at low speed. Likewise, they do not indicate the range of power factors that occur across various manufacturers models.

The Fasco data does show that for permanent split capacitor motors, power factor is relatively high and does not vary much with speed. However, for shaded pole motors, power factors are ~0.60 and decrease at low speeds. This situation is complicated by the addition of the auto-transformer. Theory (and some additional testing not included elsewhere in this report) indicates that the added inductance may actually increase (i.e., improve) power factor for permanent split capacitor motors but decrease (i.e., worsen) it for shaded pole motors. This issue is further complicated by the lack of data from motor manufacturers, especially with auto-transformer speed control.

Ignoring the change in power factor with speed for shaded pole motors underestimates savings by about 5%. However, for motors with power factors ~0.60, savings magnitudes are overestimated by about 40% (without including the effect of auto-transformer added inductive reactance) when VA is uncorrected for power factor. Overestimates of total (compressor plus fan) savings will vary with the proportion of the total savings that are derived from evaporator fan energy. For example, for test D actual overall savings are about 30% lower than reported (again, ignoring any effect that the auto-transformer has on power factor).

Annual Energy Savings Estimates

Claims made in the manufacturer's literature suggest that total operating cost savings can be as high as 50%.[6] Necsi test reports show savings of combined compressor and fan savings in the range of 10 to 60%.[4] Other claims include operating life improvements for fan motors and compressors due to reduced run times, extended product life due to better humidity control, and reduced dessication due to lower air velocities.

Although tests results show significant percentage savings under certain operating conditions, it is clear that annual savings magnitudes are highly dependent on a number of site- and system-specific factors. Savings magnitudes are driven by several factors, the primary ones being: type of evaporator motor, sizing of refrigeration system, weather profile, actual loads, and head pressure control scheme. Annual savings should be computed using techniques that account for any performance change with weather as well as oversizing of the condensing unit. If testing is done it should include tests conducted both in winter and summer conditions to establish the effect of weather on performance. Better yet, a methodology could be developed, and validated through testing, that would consider all of the relevant factors.

Appendix B: References

1. "Methods and Devices for Energy Conservation in Refrigerated Chambers," ERIP Recommendation No. 670, NIST/OTI, September 1995.
2. "Energy Savings Potential for Commercial Refrigeration Equipment," Arthur D. Little, Inc. Ref. No. 46230/NTIS PB97-128730, June 1996.
3. "Commercial Buildings Characteristics 1995, Preliminary Data" Energy Information Administration, DOE/EIA Precbecs; private communication with Joelle Davis.
4. "Refrigeration Monitoring Test Results," Nevada Energy Control Systems, Inc., various test reports, 1993-1997.
5. Fasco Industries, Private communication with John Uhrig, November 1997.
6. Specification Sheet, Necsi.

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