EXECUTIVE SUMMARY

Validating the COOLNOMIX AC and Refrigeration Compressor Control Retrofit

ESTCP Project EW-201513

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TABLE OF CONTENTS

Page

1.0 INTRODUCTION 1
2.0 OBJECTIVES 2
3.0 TECHNOLOGY DESCRIPTION 3
4.0 PERFORMANCE ASSESSMENT 4
  4.1 AIR CONDITIONING RESULTS 4
  4.2 REFRIGERATION RESULTS 6
5.0 COST ASSESSMENT 8
  5.1 AIR CONDITIONING RESULTS 8
  5.2 REFRIGERATION RESULTS 8
6.0 IMPLEMENTATION ISSUES 9

LIST OF FIGURES

Page

Figure 1. COOLNOMIX Diagram.....**Error! Bookmark not defined.**

LIST OF TABLES

Page

Table 1. Air Conditioning System Energy Performance Results 5
Table 2. Refrigeration System Energy Performance Results..... 6

1.0 INTRODUCTION

COOLNOMIX, a patented compressor control retrofit designed to reduce air conditioning and refrigeration energy consumption on systems with excess part-load capacity, was evaluated at twelve DoD test sites. On/off testing in dry and humid U.S. climates was performed for over one year on six single-zone air conditioning systems for office cooling (5-7.5 ton ducted packaged and split systems and six single-compressor (≤2.0 HP) walk-in coolers used for food service. Cooling equipment, which tends to be oversized for typical part-load operation, can waste energy when compressors run longer than necessary. Using a sensor-based relay to intelligently cycle the compressor and modulate cooling capacity, COOLNOMIX aims to supply just enough liquid refrigerant to satisfy space cooling loads, thereby reducing overall compressor runtime and saving energy. It is theoretically possible to realize savings of 15% across up to 70% of cooling energy end-uses at DoD facilities, which could yield over $60 million in annual savings, or 1.5% of total facility energy utilization.

2.0 OBJECTIVES

Our primary objective was to quantify the real-world energy and cost savings potential of the COOLNOMIX compressor control retrofit in both humid and dry climates. A demonstration was needed to evaluate energy savings claims, to understand the impact (if any) on thermal comfort, and to verify compatibility with typical U.S. cooling equipment. COOLNOMIX has been successfully deployed in other regions with notably different climates and equipment types, so it was necessary to perform a rigorous U.S. evaluation to obtain relevant savings estimates. Secondary objectives aim to verify that the technology can be readily installed, maintained, and adopted across common DoD facilities.

Energy performance was validated by submetering cooling system electricity consumption and by monitoring the indoor and outdoor conditions and relevant activity in targeted applications at each test site. Pre- and post-retrofit energy performance was assessed using and on/off testing design, alternately enabling and disabling COOLNOMIX at each site.

Cost savings estimates, evaluated based on actual energy costs, were also calculated for several DoD scenarios (based on climate and energy costs). Lifecycle cost analyses were conducted based on the hardware cost, labor and installation cost, expected maintenance, and hardware lifetime.

We do not anticipate this demonstration or technology to impact DoD regulations or standards.

To facilitate technology transfer, the U.S. distributor (CoolGreenPower, LLC.) has taken a proactive role:

1. **On-site Training** During the retrofit installations, CoolGreenPower provided on-site training of DoD maintenance personnel on how the system works, how it is installed, and how it can be removed or disabled if necessary.
2. **Best Practices and Adapt Training Materials** During the demonstration, we identified improvements to installation and operation procedures. Key lessons, summarized in this report, are being incorporated into the CoolGreenPower user and training manuals.
3. **DoD Outreach** Through active participation in trade shows and DoD meetings, the team has identified key DoD stakeholders to pursue with further outreach, pending project completion, to scale technology adoption.

To increase technology acceptance within the DoD, our project team has worked closely with the host site Energy Managers, facilities personnel, and HVAC technicians and electricians to identify adoption pathways and potential roadblocks or areas of concern. Maintenance personnel and/or facilities managers were consulted to ensure that the technology did not cause noteworthy adverse effects on the system equipment operation.

3.0 TECHNOLOGY DESCRIPTION

COOLNOMIX is a standalone compressor control retrofit for air-based vapor-compression cooling systems (Figure 1). It is installed in-line with the existing thermostat controls by an HVAC technician, requires no special integration with building automation or control systems, and does not include any networking capabilities. Compared to more involved retrofits, like variable speed motor/drive replacements, COOLNOMIX is designed to be a simpler, lower cost alternative that is practical for a wide range of existing cooling equipment.

COOLNOMIX uses two wired sensors that measure supply and return air temperature to operate a relay. The relay temporarily stops the compressor during the cooling cycle, resulting in shorter, more frequent cycles, thereby modulating cooling capacity. Ideally, this reduces the total compressor runtime and therefore reduces cooling system energy consumption.

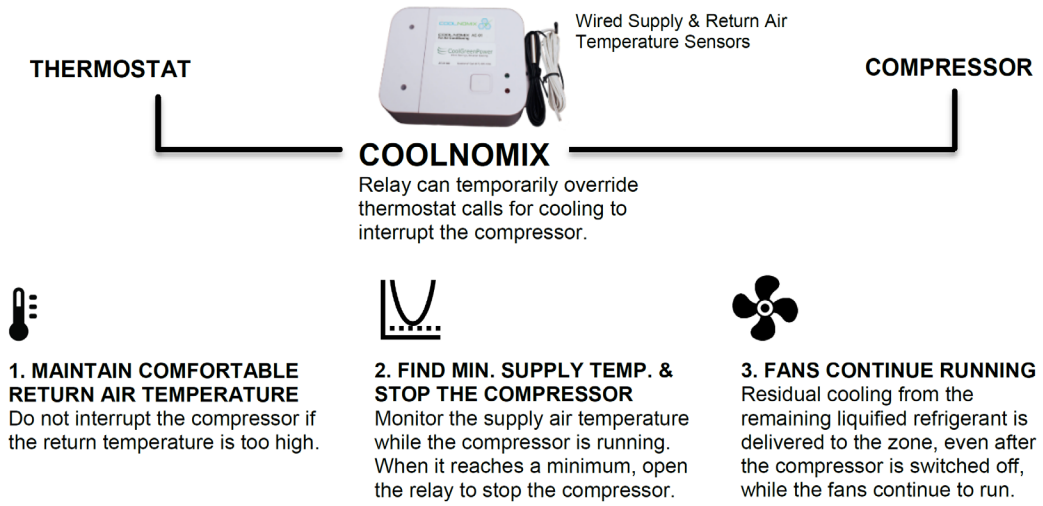

Figure 1. COOLNOMIX Diagram

The operating theory is based on optimizing the supply of liquid refrigerant. Ordinarily, when a compressor runs too long, it can flood the evaporator with excess liquid refrigerant. COOLNOMIX stops the compressor before this happens when it detects that enough liquid refrigerant has been supplied (determined by finding a minimum supply air temperature) and when the return air temperature is not too high (determined by a user-selectable setpoint). The evaporator fans continue to run as long as the thermostat calls for cooling, delivering residual cooling into the space. To prevent short-cycling, the relay remains open for a minimum lockout period (3 min.). After this period, the relay closes when the return air temperature approaches the COOLNOMIX setpoint or when the supply air temperature becomes too hot. Finally, normal operation resumes until the next cycle, when the control sequence repeats.

4.0 PERFORMANCE ASSESSMENT

Performance objectives were evaluated on the following metrics:

1. Cooling Electricity Savings (normalized savings ≥15%)
2. System Economics (simple payback period <5 years)
3. Climate Control (setpoints maintained as frequently as baseline)
4. Ease of Installation (<1 hour by a technician)
5. Reliability (% uptime, no impact on existing equipment reliability)
6. Short-cycle and Frost Prevention (features work as designed)
7. Facility Satisfaction (no facility issues)
8. Warranty Compatibility (no impact on original equipment manufacturer)

Non-cost savings metrics (3-8) were all generally satisfied. The retrofit, compatible with most of the tested equipment,[1] resulted in shorter but more frequent compressor cycles, with mild impacts on zone temperature, humidity, and thermal comfort. No obvious problems to the existing equipment were observed. Several practical implementation and installation challenges were noted, though most were not severe and could be overcome with minor technical development and/or training as described in this report.

Energy and cost metrics (1-2) showed mixed results. For walk-in refrigeration, we found no evidence of meaningful savings. For air conditioning, results varied, largely because COOLNOMIX caused fans to run much longer (often twice as long), influencing ventilation loads and incurring a steep fan energy penalty.[2] Meaningful net cooling energy savings of up to 17% were found in only two special air conditioning cases whose fans already ran most of the time. In other cases, cooling energy use increased because of increased fan runtime.

4.1 AIR CONDITIONING RESULTS

Cost-effective energy savings were identified in only one special air conditioning case – the only case whose baseline ventilation fans were programmed to run all the time. Energy savings were about 4,030 kWh/yr (25% of condenser and 17% of total cooling system energy use).[3] See Section 5.0 for cost savings.

[1] One of six air conditioning sites did not apparently control the compressor due to an unknown fault.

[2] Single-zone ducted cooling systems, common in the U.S., tend to also control high-powered ventilation fans. In contrast, many overseas applications involve VRV/VRF and mini-/multi-split systems, with smaller evaporator fans and no ventilation fans. Fan penalties in those cases were much less significant.

[3] During the initial testing period, when COOLNOMIX was incorrectly configured to control the first stage compressor only, energy savings were positive, but much lower (5.7% condenser and 3.8% system).

Table 1. Air Conditioning System Energy Performance Results

Site	Climate	Regression Terms	R^2	CV-RMSE	Energy Change		Notes
					(kWh/yr)	%	
AC1	DRY	CDD, Occupancy	0.80	0.13	+1,691	+15	Significant increase due to extra fan runtime.
AC2	DRY	CDD, Occupancy	0.89	0.08	-1,522	-6.5	Significant savings, but below target. System slightly undersized.
AC3	DRY	CDD, Occupancy	0.84	0.14	-4,030	-17	Significant savings, met target. Dual stage condenser. Ventilation fans always on.
AC4	HUMID	CDD, Occupancy	0.89	0.14	-	-	COOLNOMIX effect not significant.
AC5	HUMID	CDD, Occupancy	0.88	0.17	+2,544	+26	Significant increase due to extra fan runtime. Condenser energy not significantly changed.
AC6	HUMID	CDD, Occupancy	0.68	0.30	-	-	No compressor control observed.

Notes: Cooling System Energy Change = (Baseline – COOLNOMIX). Includes ventilation fans and condenser. Statistically significant savings highlighted

Results for this successful case come with two caveats. First, they were based on a shorter testing period with limited shoulder season data. Second, cycling both condensers together led to slightly elevated afternoon zone temperature (about 2°F higher). The energy regressions control for this difference, though occupant comfort could be adversely affected. Nevertheless, savings were statistically significant, and these results suggest promise for niche applications where the evaporator and ventilation fans need to run continuously.

Statistically significant savings (9.9% condenser, 6.5% system, 1,522 kWh/yr net) were also identified in a second air conditioning case; however, these were below the success target and are unlikely to be cost effective. This case was unique for being slightly undersized, with fans that ran frequently in the baseline, so that the fan penalty was lower than in other cases. These two cases suggest net-positive savings are possible when fans must run frequently in the baseline.

In all other cases, COOLNOMIX caused the fans to run a far greater portion of the time, incurring a significant electricity penalty. This increased the average ventilation rates, having mixed effects on cooling loads. The net effect in most cases was no discernable change in condenser energy use and a substantial increase in fan electricity consumption.

Several factors contributed to the mixed results for air conditioning.

1. Large ventilation fans, common to split-system air handlers and packaged roof top units in the U.S., ran significantly longer with COOLNOMIX, leading to higher and more variable ventilation loads and steep fan energy penalties.
2. Some cooling systems had limited excess part-load capacity. None were grossly oversized, one was marginally undersized, and many were older and/or poorly maintained (e.g., low

refrigerant charge, clogged fan filters, loose fan belt). Older systems, common at many DoD facilities, are more likely to experience issues that reduce their capacity. Without significant excess part-load capacity, savings opportunity is limited.

3. The existing thermostats were well positioned, loads were not extremely variable, and spaces were not grossly overcooled in the baseline, further limiting savings opportunity. Using the COOLNOMIX return air sensor to control space temperature, therefore, did not significantly change or improve the zone temperature control.

4.2 REFRIGERATION RESULTS

In most refrigeration cases, energy consumption did not change significantly or meaningfully. The best-case scenario demonstrated a 5% reduction in compressor energy use (3% of total refrigeration system energy). This savings totaled about 100 kWh/yr, well below the economically viable threshold.

Table 2. Refrigeration System Energy Performance Results

Site	Climate	Regression Terms	R^2	CV-RMSE	Energy Change		Notes
					(kWh/yr)	%	
REF1	DRY	T_{out}, Occupancy	0.67	0.18	-96	-2.0	Significant savings, well below target.
REF2	DRY	T_{out}, Occupancy	0.60	0.16	-63	-1.1	Savings not statistically significant.
REF3	DRY	T_{out}, Occupancy	0.74	0.16	-95	-1.1	Savings not statistically significant.
REF4	HUMID	T_{out}, Occupancy	0.45	0.17	+110	+3	Increase not statistically significant.
REF5	HUMID	T_{out}, Occupancy	0.40	0.21	+142	+4	Increase statistically significant.
REF6	HUMID	T_{out}, Occupancy	0.57	0.09	-101	-3	Significant savings, well below target.

Notes: Cooling System Energy Change = (Baseline – COOLNOMIX). Includes evaporator fans and compressor.
Tout = outside air temperature. Statistically significant savings highlighted.
Excludes evaporator fan penalty on REF4-5, up to +300 kWh/yr.

Several factors contributed to the absence of meaningful refrigeration savings:

1. Baseline compressor cycles were already fairly short (typ. <10 min.), limiting the amount they could be reduced.
2. Two coolers had an evaporator fan control strategy that reduced fan speed during off-cycles to save energy. COOLNOMIX caused these fans to run mostly at full speed, leading to significantly higher fan energy use (about 300 kWh more per year).
3. Off-cycle defrost was implemented on all coolers, so no energy benefit was observed related to frost prevention. Frosting issues were not observed in the baseline, so there was also no apparent frost prevention benefit.
4. Compressor energy consumption in the walk-in coolers was relatively low (all <8,000 kWh/yr), making cost effectiveness unlikely even if 15% savings were achieved.

As a result, the single-compressor walk-in coolers we tested do not represent cost-effective target applications.

5.0 COST ASSESSMENT

5.1 AIR CONDITIONING RESULTS

For the one cost-effective site (AC3), we estimate a simple payback period (SPP) of 4.1 years, a savings-to-investment ratio (SIR) of 1.8, and a lifecycle cost savings (LCCS) of $1,270 based on a 10-year measure life, a $0.06/kWh electricity rate, and a 3% discount rate. Doubling the electricity rate yields SPP 2.1, SIR 4.9, and LCCS $3,505.

5.2 REFRIGERATION RESULTS

Since energy consumption did not change significantly or meaningfully in most refrigeration cases, the savings were well below the economically viable threshold.

6.0 IMPLEMENTATION ISSUES

For the walk-in cooler refrigeration cases, the baseline compressor energy consumption was generally too small to justify cost effective savings even if the savings targets were achieved. Furthermore, although COOLNOMIX caused the compressors to run with shorter cycles, the net effect on refrigeration consumption was negligible in most cases, with savings far below the target. Consequently, we do not recommend further pursuit of this refrigeration application.

For air conditioning, significant savings were achieved only in special cases where ventilation fans already ran most of the time. Additional hardware development is needed to greatly reduce the fan energy penalty on ducted packaged rooftop unit and split-system configurations before further testing or deployment is performed. Promising results from the two successful cases suggests potentially significant energy savings if this fan issue can be resolved. At the time of publication, the COOLNOMIX manufacturer and U.S. vendor were pursuing new installation strategies to overcome these technical challenges; however, results from their preliminary tests were not yet available.