AEEM HVAC ENERGY VALVE

Disconnect-Side Adaptive HVAC Energy Optimization

Consumer retrofit whitepaper - measurement, adaptive control, fault detection, bill reduction, and a safe installation architecture for residential split-system HVAC.

Core premise: optimize the HVAC system around the compressor, not the utility waveform.

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1. Executive Summary

The AEEM HVAC Energy Valve is a professionally installed, line-side HVAC monitoring and control module intended for placement immediately upstream of the existing outdoor air-conditioning or heat-pump disconnect, or eventually as a listed disconnect/controller assembly that retains a manual service-disconnect function. Its purpose is not to claim "power conditioning" savings. Its purpose is to measure the outdoor unit as an electrical machine, learn the home and equipment, reduce avoidable runtime and cycling, coordinate demand, and identify maintenance faults that cause the system to run longer than necessary.

This placement is commercially attractive because essentially all compressor and condenser-fan electrical consumption passes through one measurable point. It also avoids needing a smart plug on every appliance. The module becomes an HVAC submeter, diagnostic sensor, demand controller, and optimization endpoint in one enclosure.

ENERGY STAR reports that heating and cooling account for almost half of an average household energy bill and more than $900 per year, while certified smart thermostats save about 8% of heating and cooling bills on average. DOE research materials also identify adaptive/autonomous controls as having material HVAC savings potential. These benchmarks support a conservative product target: 5-12% HVAC-energy reduction in suitable homes from adaptive operation alone, with higher total savings possible when the product detects and prompts correction of real maintenance or airflow faults.

Outcome	Whitepaper target
Installation point	Upstream of existing outdoor disconnect; future integrated listed disconnect/controller variant
Primary measurable load	Outdoor compressor + condenser fan; optional indoor blower/thermostat integration
Savings mechanism	Runtime/cycling optimization, tariff shifting, demand limiting, fault detection, maintenance verification
Target adaptive savings	5-12% HVAC energy in suitable homes after learning; not guaranteed
High-opportunity homes	10-20%+ possible when poor schedules, short cycling, dirty coils/filters, charge/airflow issues, or expensive tariff windows are corrected
Learning horizon	Useful control in 7-14 days; stable home/equipment model in 30-60 days; seasonal refinement over 90+ days

2. Installation Architecture

2.1 Preferred retrofit location

For the first product, the preferred topology is:

Branch circuit -> AEEM HVAC Energy Valve -> Existing HVAC disconnect -> Outdoor unit

This preserves the conventional service disconnect next to the equipment while giving the Energy Valve a continuous measurement point ahead of it. A later product may combine control and disconnect functions only if it is specifically listed/certified for that role and preserves required manual isolation and working-clearance functions.

NEC 440.14 requires the air-conditioning/refrigeration disconnecting means to be within sight from and readily accessible from the equipment. Therefore the product architecture should not hide, defeat, or remotely substitute for the service disconnect. Installation should be performed by a qualified electrician/HVAC professional under the locally adopted electrical code and equipment instructions.

2.2 Why line-side placement is useful

- Captures compressor starts, running watts, voltage sag, current, and condenser-fan operation at one point.
- Enables true HVAC energy submetering without opening the refrigeration circuit.
- Allows fault signatures to be correlated with outdoor temperature, indoor temperature, humidity, thermostat calls, and runtime.
- Provides a safe hard-stop output for demand response or protective control when the equipment/control scheme permits it.
- Creates a standardized retrofit node that can communicate with thermostat, indoor air-handler sensors, utility rate data, solar, battery, or EV systems.

3. Hardware Definition

Subsystem	Function
Revenue-grade-class metering target	True RMS V/I, real power, energy, power factor, frequency, start current profile
Contactor/relay interface	Control permitted HVAC calls or an external rated contactor; never interrupt compressor arbitrarily without anti-short-cycle logic
Temperature sensors	Enclosure/terminal temperature; optional line-set/ambient probes for diagnostic correlation
Ambient sensor	Outdoor temperature/humidity at condenser
Indoor/thermostat bridge	Call state, indoor temperature/humidity, occupancy/setpoint context
Local processor	Learns baseline and executes safety constraints locally
Connectivity	Wi-Fi/Thread/Matter-class telemetry; cloud optional, not required for protection
Fail-safe behavior	Loss of network must not disable normal HVAC unless an explicit protective fault exists

4. What the Product Can Actually Improve

The Energy Valve should distinguish thermodynamic equipment efficiency from effective operating efficiency. A line-side controller cannot turn a 14-SEER machine into a 20-SEER machine by altering voltage. It can, however, improve how efficiently the installed system converts purchased electricity into useful comfort over time.

Optimization	Mechanism	Expected effect
Anti-short-cycle enforcement	Avoids rapid restart and inefficient transient operation	Lower starts, less wear, modest energy benefit
Adaptive setback/recovery	Learns house thermal response and chooses economical recovery timing	Primary direct energy-saving mechanism
Weather-aware control	Uses outdoor conditions to avoid unnecessary pre-cooling/heating	Reduces runtime without comfort loss
Tariff-aware scheduling	Shifts permitted runtime/preconditioning around TOU peaks	Bill reduction may exceed kWh reduction
Peak coordination	Avoids simultaneous HVAC + EV/water-heater peaks when possible	Demand/peak reduction
Fault detection	Flags rising watts per degree-hour, long runtime, abnormal starts	Prevents hidden degradation from persisting
Maintenance verification	Measures before/after coil/filter/service performance	Turns maintenance into quantified savings

5. Adaptive Learning Model

The controller should learn a compact physical model of each home rather than rely on generic schedules. The fundamental response variable is useful temperature/humidity change per unit of HVAC energy under comparable outdoor conditions.

Learning period	What is learned	Control authority	Expected share of eventual adaptive savings
Days 0-3	Electrical signatures, thermostat calls, compressor start/run pattern	Monitor only or very conservative	0-10%
Days 4-7	Basic thermal response vs outdoor temperature; occupancy rhythm	Anti-short-cycle + simple schedule improvements	15-35%
Days 8-14	Recovery time, overshoot, daily load shape, comfort tolerance	Adaptive start/stop and setback	35-60%

Days 15-30	Weather-normalized energy-per-degree model, fault baseline	Full normal optimization	60-85%
Days 31-60	House thermal inertia, shoulder-season behavior, tariff response	Stable personalized operation	80-100%
90+ days	Seasonal/defrost/heat-pump behavior and long-term degradation	Seasonal refinement + predictive maintenance	Maintains or improves savings

A practical product should expose confidence. It should not optimize aggressively until it has enough comparable cycles, and it should revert to standard thermostat behavior whenever sensor confidence is low.

6. Estimated Monthly Savings and Effective Efficiency Increase

The following estimates are planning ranges, not promises. ENERGY STAR states that average U.S. heating/cooling spending is more than $900 per year, which is roughly $75 per month when averaged across the year. Actual summer/winter HVAC months can be much higher, so month-by-month dollar savings will be seasonal.

Scenario	HVAC energy/cost reduction	Average annualized monthly savings on $900/yr HVAC spend	Interpretation
Already optimized home	3-5%	$2.25-$3.75/mo	Mostly monitoring, small scheduling gains
Baseline product target	5-8%	$3.75-$6.00/mo	Comparable to or modestly below/around smart-thermostat benchmark
Good adaptive fit	8-12%	$6.00-$9.00/mo	Strong schedule/recovery optimization
High-opportunity home	12-20%	$9.00-$15.00/mo	Requires substantial controllable waste and/or maintenance corrections
Fault-remediation case	Potentially >20% during affected months	Highly variable	Not credited until fault is confirmed and repaired

For a household spending $1,500 per year on HVAC electricity, the same 8-12% target equals about $10-$15 per month averaged across the year; at $2,400 per year, it equals about $16-$24 per month. Savings concentrate in heavy heating/cooling months.

6.1 Effective efficiency metric

AEEM should report an "effective operating efficiency" index instead of claiming a change to the nameplate SEER/HSPF/COP. One defensible form is:

$$\text{EOE} = \textbf{Weather-normalized useful degree-hours maintained / HVAC kWh consumed}$$

If comfort and outdoor conditions are equivalent and the system uses 10% fewer kWh, effective operating efficiency has improved by approximately 11.1% relative to the old energy-per-service ratio (because useful output per kWh is the reciprocal of kWh per useful service). For product communication, however, AEEM should normally report the simpler measured kWh and dollar reduction.

Measured HVAC energy reduction	Approx. increase in useful-service-per-kWh index
3%	3.1%
5%	5.3%
8%	8.7%
10%	11.1%
12%	13.6%
15%	17.6%
20%	25.0%

7. Learning Time x Expected Savings Ramp

Assuming a home ultimately proves capable of 10% HVAC-energy reduction, a reasonable conservative commissioning model is:

Time since install	Illustrative achieved reduction	Monthly equivalent on $75 average HVAC spend	Reason
Week 1	0-2%	$0-$1.50	Baseline and protection learning
Week 2	2-5%	$1.50-$3.75	Schedule + recovery model becomes usable
Weeks 3-4	5-8%	$3.75-$6.00	Weather normalization and pattern confidence
Months 2-3	8-10%	$6.00-$7.50	Stable personalized control
After 3 months	~10% target, variable	$7.50 average annualized	Seasonal refinement; faults may add separate savings

In a $1,500/year HVAC-cost home, the same 10% mature reduction averages $12.50/month; in a $2,400/year HVAC-cost home it averages $20/month. The controller should show realized savings rather than assuming the target was achieved.

8. Maintenance and Fault Detection as a Second Savings Engine

ENERGY STAR warns that dirty filters restrict airflow and make HVAC systems work harder, while dirty coils reduce cooling ability and increase runtime and energy cost. Incorrect refrigerant charge also reduces efficiency. These conditions are important because a disconnect-side meter can see their electrical consequences even though it cannot directly diagnose every refrigeration fault by current alone.

The product should therefore use anomaly detection to trigger a qualified inspection, not pronounce a refrigerant or airflow diagnosis by itself. Examples:

- Runtime per cooling degree rises 15% at comparable outdoor conditions.
- Compressor power remains similar but indoor recovery time worsens.
- Start current/starting duration changes materially from the learned baseline.
- Outdoor-unit watts rise while delivered temperature response falls.
- System begins cycling more frequently than its normal pattern.

After maintenance, the system should measure the same metrics again. This before/after verification can convert otherwise vague maintenance advice into quantified household savings.

9. Product Economics

Item	Planning target
Hardware retail	$149-$299 for outdoor Energy Valve electronics/enclosure
Professional installation	$150-$400 typical planning allowance; market-dependent
Optional thermostat/indoor sensors	$50-$150
Target installed cost	$300-$700 initial product range
Simple-payback requirement	Prefer <3-5 years in target homes, or bundle diagnostics/maintenance value
Best first customers	Electric heat pumps/AC, high summer bills, TOU rates, solar/EV homes, aging systems

At only $6/month savings, a $500 installed product has a long energy-only payback. Therefore the product should not be sold purely as a generic saver to every household. It is most compelling where annual HVAC spend is high, tariff shifting is valuable, or diagnostics prevent a significant maintenance/repair penalty. A lower hardware/installation cost materially improves the business case.

10. Electrical, HVAC, and Safety Constraints

This is line-voltage HVAC equipment and must be designed as such. The whitepaper intentionally does not provide DIY mains-installation instructions. Production hardware requires appropriate listing/certification, rated enclosures and terminals, short-circuit and overcurrent coordination as applicable, temperature-rise testing, surge immunity, creepage/clearance, and documented compatibility with compressor controls.

- Do not interrupt a running compressor casually; all control must respect manufacturer timing and anti-short-cycle constraints.
- Do not defeat the existing local service disconnect.

- Loss of communications should default to safe normal HVAC operation.
- Protective functions must execute locally, not depend on cloud connectivity.
- Variable-speed/inverter systems require manufacturer-compatible demand/control interfaces rather than crude line switching.
- Heat pumps require special handling of defrost, auxiliary heat, and compressor lockout logic.

11. Product Family

Variant	Best use
Valve-Monitor	Metering + diagnostics only; lowest certification/control risk
Valve-Control	Metering + thermostat/demand coordination; first full consumer product
Valve-Disconnect	Future integrated listed service disconnect + controller
Valve-HeatPump	Adds defrost/aux-heat and variable-capacity integration
Valve-Pro	Contractor dashboard, commissioning and before/after service verification

12. Development and Validation Plan

Stage	Sample	Primary gate
Bench	3-5 HVAC electrical profiles / simulator loads	Meter accuracy, switching safety, no nuisance control
Pilot A	10 homes, monitor-only 30 days	Stable signatures and weather-normalized baseline
Pilot B	25-50 homes, adaptive control 90 days	>=5% median HVAC kWh reduction in target cohort
Pilot C	100+ homes, full season	Savings persist after weather/occupancy normalization
Commercial beta	Multi-climate / heat-pump mix	Low complaint rate, safe fault handling, credible payback segmentation

The key scientific requirement is randomized or crossover testing where feasible. Each home should spend comparable periods in baseline and adaptive modes, with weather normalization and comfort constraints held constant. Otherwise normal seasonal changes can be mistaken for product savings.

13. Consumer Positioning

The product should be sold as an HVAC intelligence layer, not an electrical miracle device.

"Your HVAC already has a disconnect. Make that point intelligent."

The consumer sees: HVAC cost today, projected monthly cost, dollars saved by adaptive control, abnormal-runtime alerts, service verification, and a clear confidence score. Contractors see electrical signatures, runtime history, outdoor conditions, service before/after comparisons, and fault trends.

14. Evidence Base and References

1. **ENERGY STAR, Smart Thermostats FAQs:** ENERGY STAR states certified smart thermostats save approximately 8% of heating and cooling bills, about $50/year on average. https://www.energystar.gov/products/heating_cooling/smart_thermostats/smart_thermostat_faq
2. **ENERGY STAR, Smart Thermostats / Home Energy:** ENERGY STAR states almost half of the average American household energy bill goes to heating and cooling, more than $900/year. https://www.energystar.gov/products/energy_star_home_upgrade/smart_thermostats
3. **ENERGY STAR, HVAC Maintenance Checklist:** Dirty coils can reduce cooling ability, increase runtime and energy cost; improper refrigerant level reduces efficiency. https://www.energystar.gov/saveathome/heating-cooling/maintenance-checklist
4. **ENERGY STAR, Heat & Cool Efficiently:** Dirty filters restrict airflow and cause HVAC equipment to work harder and waste energy. https://www.energystar.gov/saveathome/heating-cooling
5. **U.S. DOE Building Science Education, HVAC Programmable Thermostats:** Smart and programmable controls save energy by adjusting operation based on schedules, occupancy and activity. https://bsesc.energy.gov/energy-basics/hvac-programmable-thermostats
6. **U.S. DOE, Emerging Technologies R&D (2019):** DOE research planning materials identify adaptive/autonomous controls and a residential/commercial HVAC savings technical potential around 17%; this is a research potential, not a consumer-product guarantee. https://www.energy.gov/sites/prod/files/2019/04/f61/bto-sc-rdo-041519.pdf
7. **NFPA / NEC Article 440.14 materials:** The HVAC disconnecting means is required to be within sight from and readily accessible from the equipment; local adopted code and listing requirements govern installation. https://docinfofiles.nfpa.org/files/AboutTheCodes/70/70_A2025_NEC_P11_70-48_AmendBallotFinal.pdf

15. Formal Outcome

The highest-probability HVAC consumer product emerging from AEEM is a disconnect-side adaptive energy and diagnostics node installed upstream of the existing outdoor HVAC disconnect. It uses direct whole-unit electrical measurement plus thermostat, weather, and optional indoor sensing to learn the home, reduce avoidable HVAC runtime, coordinate demand, and identify efficiency degradation.

A mature target of 5-12% HVAC-energy reduction is reasonable for suitable homes as an engineering objective, with approximately 7-14 days required for useful adaptation and 30-60 days for a stable personalized model. Higher savings should be attributed only when measured data demonstrate actual controllable waste or a corrected equipment fault. The product should report realized kWh and dollar savings continuously and never imply that line-side electronics change the equipment nameplate efficiency.