OpenADR 3.0 Demand Flexibility for Heat Pump Water Heaters

IEA EBC Annex 96 — Activity A3

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Outline

1. **Introduction** — Motivation and goals
2. **Background** — OpenADR 3.0, demand flexibility, HPWHs
3. **Use Case** — Price-responsive HPWH control through OpenADR
4. **Software Architecture** — Components and data flow
5. **Implementation** — Easy Shift algorithm and CTA-2045 integration
6. **How to Use** — Setup, run, and extend

1. Introduction

Why Demand Flexibility?

- Grid decarbonization requires flexible loads that can **shift consumption**
- Water heating accounts for **~18% of residential energy use** in the US
- Heat pump water heaters (HPWHs) with storage tanks are ideal candidates:
  - Thermal storage enables **load shifting** without impacting comfort
  - Can pre-heat during cheap/clean hours, coast during expensive/dirty hours
- **Challenge:** How do we communicate price signals to devices at scale?

Project Goals

Develop an **open-source software toolkit** so that researchers and practitioners can:

1. Set up an OpenADR 3.0 communication infrastructure (VTN + VEN)
2. Fetch real electricity pricing data and publish it as OpenADR events
3. Run a control algorithm that converts price signals into HPWH schedules
4. Generate CTA-2045 demand response commands for water heaters
5. Test the full pipeline end-to-end on their own machines

> All code, documentation, and quickstart notebooks are publicly available.

2. Background

OpenADR 3.0

Open Automated Demand Response — an open standard for communicating DR signals.

Concept	Description
VTN (Virtual Top Node)	Server — publishes programs, events, price signals
VEN (Virtual End Node)	Client — receives signals, controls devices
Program	Defines a demand response program (e.g., dynamic pricing)
Event	Time-based signal with payload (e.g., hourly prices)
Report	Telemetry data sent from VEN back to VTN

REST API (JSON over HTTP) with OAuth 2.0 authentication

Heat Pump Water Heaters as Flexible Loads

How HPWHs provide flexibility:

- Tank stores thermal energy (50–80 gal)
- Heat pump COP of 3–4x vs resistance
- Can **pre-heat** during low-price hours, **coast** during high-price hours
- No comfort impact if managed well

Parameter	Typical Value
Tank capacity	50–80 gallons
HP output	4–5 kW thermal
COP	2.5–4.5
Thermal storage	8–15 kWh

CTA-2045 and Device Communication

CTA-2045 is a modular communications interface for energy devices, providing standardized demand response commands for water heaters:

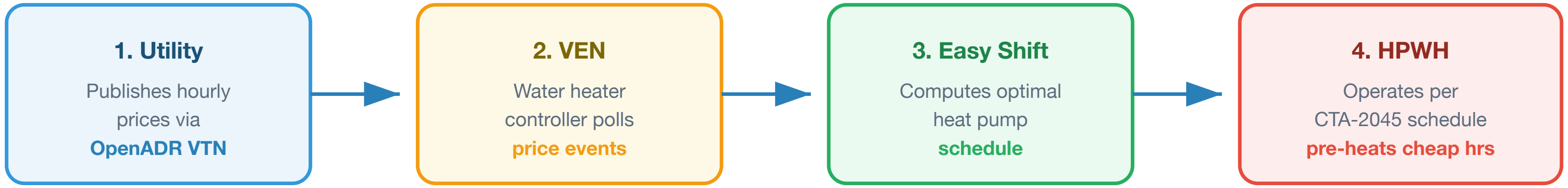
Signal	Code	Water Heater Action
Shed	-1	Lower setpoint, disable HP — coast on stored energy
Normal	0	Default operation
Load Up	1	Raise setpoint, pre-heat the tank
Adv. Load Up	2	Max setpoint, tight deadband

This project covers the full pipeline: **OpenADR → Control Algorithm → CTA-2045**

3. Use Case

Price-Responsive HPWH Control Through OpenADR

Scenario: A utility publishes dynamic electricity prices. A water heater controller receives these prices and optimizes its operation schedule.



1. Utility
Publishes hourly prices via **OpenADR VTN**

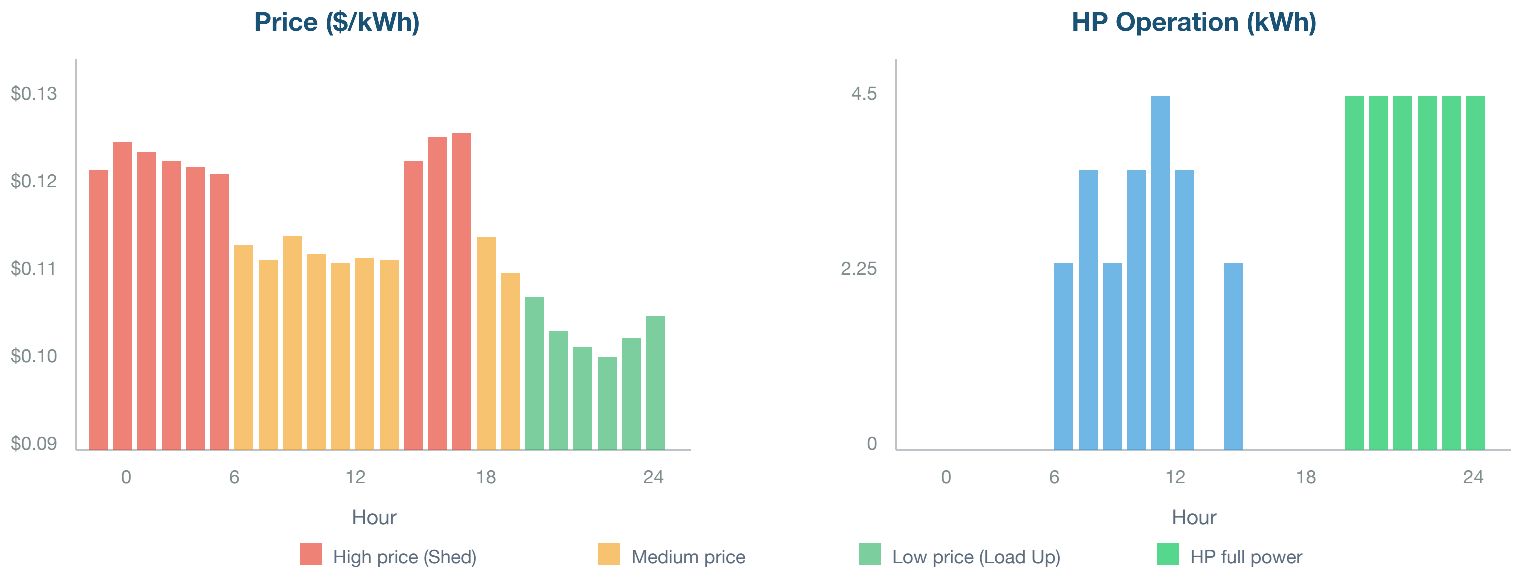
2. VEN
Water heater controller polls **price events**

3. Easy Shift
Computes optimal heat pump **schedule**

4. HPWH
Operates per CTA-2045 schedule **pre-heats cheap hrs**

OpenADR 3.0 Price Signal → Easy Shift Algorithm → CTA-2045 Commands → Device Action

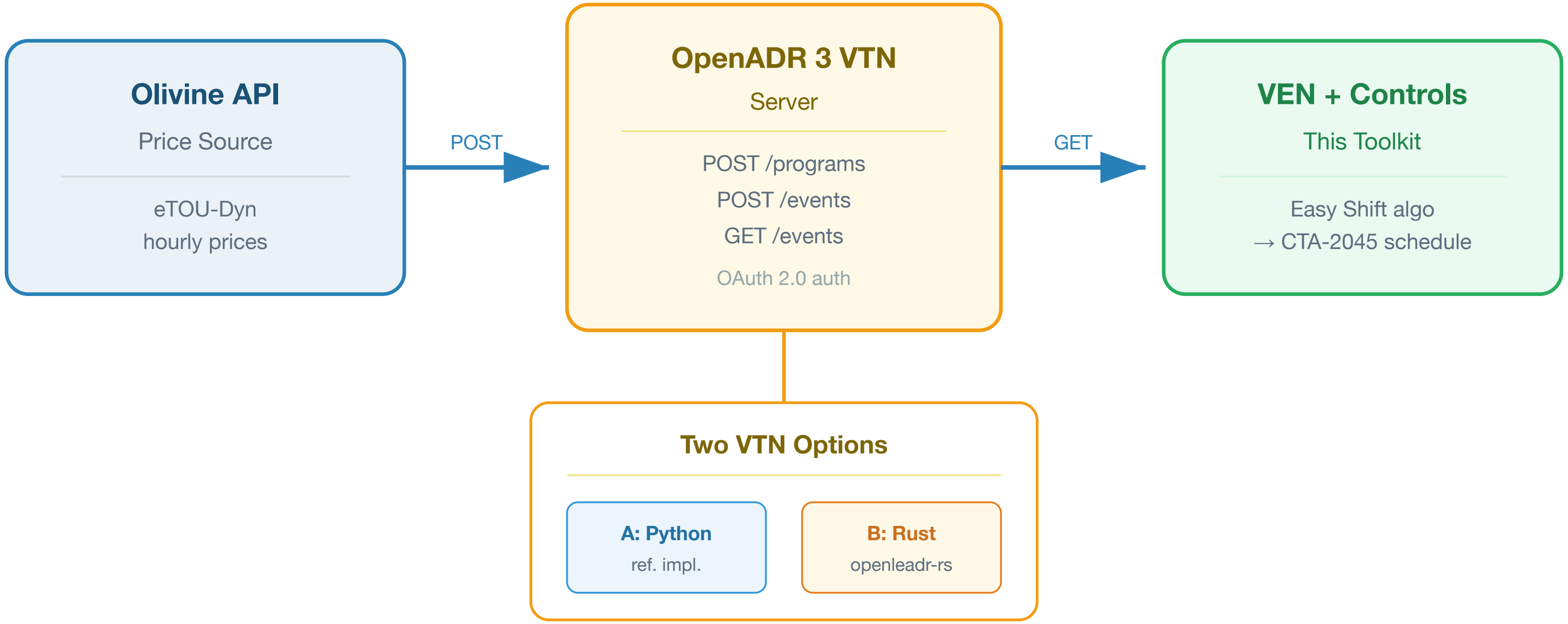
Example: 24-Hour Price Signal and Response



Result: Same hot water delivered at lower cost by shifting to cheap hours.

4. Software Architecture

System Architecture



Repository Structure

```
annex96-a3-hotwater/
├── README.md                         # Project overview
├── requirements.txt                  # Python dependencies
├── instructions.ipynb                # Setup: Python VTN
├── instructions-openleadr.ipynb      # Setup: openleadr-rs VTN
├── quickstart.ipynb                  # Demo: Python VTN
├── quickstart-openleadr.ipynb        # Demo: openleadr-rs VTN
├── controls/                         # Control algorithms
│   ├── easy_shift.py                 # Easy Shift scheduling
│   └── cta2045.py                    # CTA-2045 schedule generation
├── sample_data/                      # Example JSON payloads
└── presentation/                     # This presentation
```

Two VTN Options

	Python VTN Ref. Impl.	openleadr-rs (Rust)
Language	Python (Flask)	Rust (Axum)
Database	In-memory	PostgreSQL (Docker)
Auth	`bl_client/1001`	`any-business`
Base URL	`localhost:8080/openadr3/3.0.1`	`localhost:3000`
Access	Contact for access	Open source
Best for	Quick local testing	Production-like setup

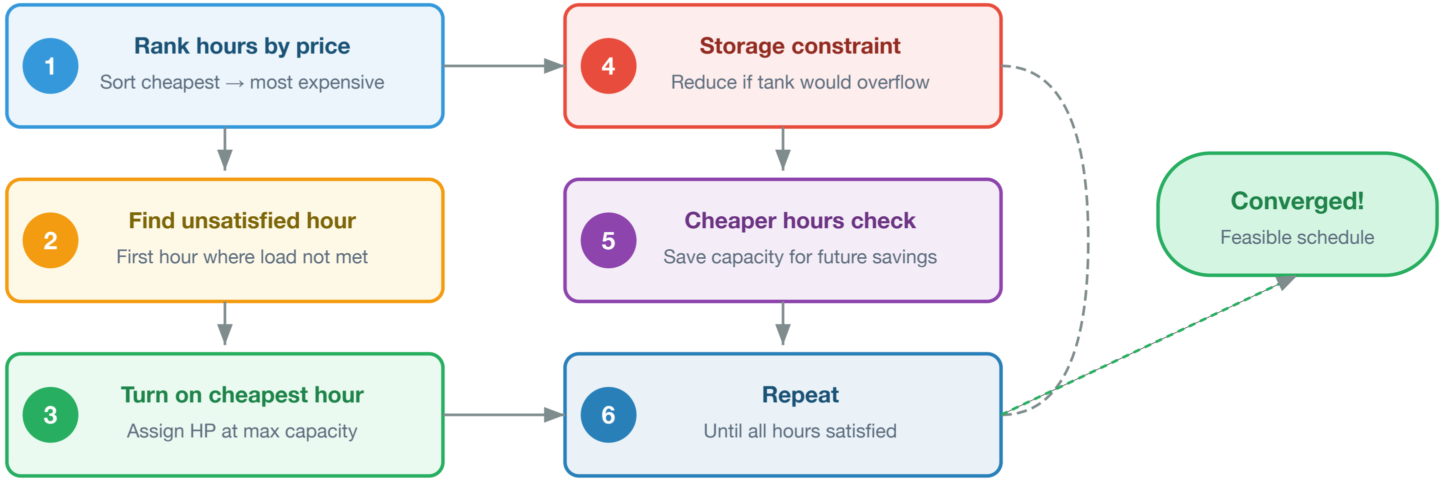
5. Implementation

Easy Shift Algorithm

EASY-SHIFT — Equipment Scheduling Algorithm for Thermal Energy Storage with Load Shifting

B. Woo-Shem and P. Grant, LBNL

Core idea: Rank hours by electricity cost and iteratively assign HP operation to the cheapest available hours while respecting storage constraints.


1
Rank hours by price
Sort cheapest → most expensive
2
Find unsatisfied hour
First hour where load not met
3
Turn on cheapest hour
Assign HP at max capacity
4
Storage constraint
Reduce if tank would overflow
5
Cheaper hours check
Save capacity for future savings
6
Repeat
Until all hours satisfied
Converged!
Feasible schedule

Near-optimal scheduling without full optimization solvers

Easy Shift: Key Constraints

Storage Capacity

- Tank has maximum thermal storage (e.g., 12 kWh)
- If running at full power would exceed max storage → reduce output
- Maintains a minimum reserve for unexpected demand

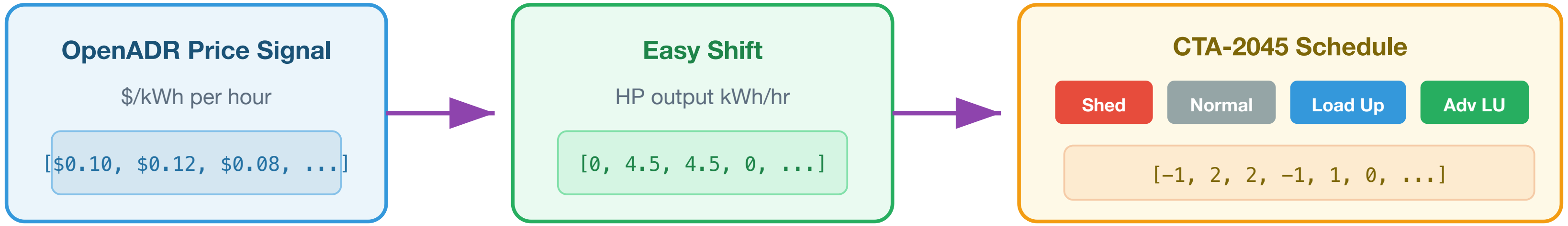
Cheaper Hours Optimization

- After satisfying the current hour, check: is there a cheaper hour ahead?
- If yes, reduce current output to save capacity for the cheaper hour

Convergence

- Returns `converged = True/False` as a flag to trigger fallback strategies

CTA-2045 Schedule Generation



Full pipeline: prices → optimal schedule → device commands

> Two approaches available: from Easy Shift output (uses HP output levels), or directly from prices (uses percentile thresholds).

Quickstart Demo Pipeline

```python
# Step 1: Authenticate with VTN
token = get_token("bl_client", "1001")

# Step 2: Fetch prices from Olivine API
olivine_data = requests.get(OLIVINE_PRICING_URL).json()

# Step 3: Create pricing program on VTN
requests.post(f"{VTN}/programs", json=program_data, headers=auth)

# Step 4: Publish price event
requests.post(f"{VTN}/events", json=event_data, headers=auth)

# Step 5: Read events as VEN
events = requests.get(f"{VTN}/events", headers=ven_auth).json()

# Step 6: Run Easy Shift → Step 7: Generate CTA-2045 schedule
operation, converged = easy_shift(parameters)
cta_schedule = easy_shift_to_cta2045(operation, parameters)
```

Example Output

```
Hourly schedule (kWh):
  Hour  0: OFF   0.00 kWh  @ $0.12052/kWh   →  Shed
  Hour  1: OFF   0.00 kWh  @ $0.12227/kWh   →  Shed
  Hour  2: OFF   0.00 kWh  @ $0.12213/kWh   →  Shed
  Hour  3:  ON   1.50 kWh  @ $0.12132/kWh   →  Normal
  ...
  Hour 19:  ON   4.50 kWh  @ $0.10689/kWh   →  Advanced Load Up
  Hour 20:  ON   4.50 kWh  @ $0.10519/kWh   →  Advanced Load Up
  Hour 21:  ON   4.50 kWh  @ $0.10300/kWh   →  Advanced Load Up

Total electricity cost: $0.62145
```

Shifts operation to cheapest hours (19–23) and generates CTA-2045 commands.

6. How to Use This Software

Quick Setup

1. Clone and install

```
git clone <repository-url>
cd annex96-a3-hotwater
pip install -r requirements.txt
```

2. Start a VTN (choose one)

Option A: Python VTN (contact anandkrp@andrew.cmu.edu for access)

```
cd openadr3-vtn-reference-implementation
virtualenv venv && source venv/bin/activate
pip install -r requirements.txt && python -m swagger_server
```

Option B: openleadr-rs (open source — see `instructions-openleadr.ipynb`)

Run the Quickstart

3. Launch the notebook

```
jupyter notebook quickstart.ipynb           # for Python VTN
jupyter notebook quickstart-openleadr.ipynb  # for openleadr-rs
```

4. What the notebook does

Step	Action
1–2	Connect to VTN, fetch live prices from Olivine API
3–4	Create pricing program, publish hourly price event
5	Read events as a VEN
6	Run Easy Shift and plot optimal schedule
7	Generate CTA-2045 command schedule

Extending the Software

- **Customize HPWH parameters** — Edit Step 6: tank size, HP capacity, COP, draw profile
- **Use your own price data** — Replace Olivine API with your own source
- **Add new control algorithms** — Create a new file in `controls/`
- **Integrate with CTA-2045 hardware** — Connect generated schedules to physical devices
- **Connect to a real VEN** — Replace notebook HTTP calls with a persistent VEN client

Resources and References

- **Repository:** `annex96-a3-hotwater/`
- **OpenADR 3.0.1 Spec:** included in repo, or openadr.org
- **openleadr-rs:** github.com/OpenLEADR/openleadr-rs
- **Olivine API:** `api.olivineinc.com/i/oe/pricing/signal/paced/etou-dyn`
- **Easy Shift:** B. Woo-Shem and P. Grant, "EASY-SHIFT: Equipment Scheduling Algorithm for Thermal Energy Storage with Load Shifting," LBNL. Presentation

Thank You

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All source code and documentation available in the `annex96-a3-hotwater` repository