TUNE-UP ACCELERATOR PROGRAM

An Introduction to OpenEIS

Pacific Northwest National Laboratory

OpenEIS (Open Energy Information System) is an open-source software tool for analyzing building energy and operational data to identify efficiency improvement opportunities. Continuous monitoring and analysis can increase whole building energy efficiency by up to 20%. However, most building managers and operators do not have cost-effective access to commercial tools and algorithms for identifying potential savings. Conversely, diagnostic methods developed by the Department of Energy's National Laboratories, by university researchers, and by publicly funded research projects do not have a common distribution path by which to put new tools in the hands of building managers and their operations staff.

In response, OpenEIS was created to provide standard methods for authoring, sharing, testing, using, and improving algorithms for operational building energy efficiency with building managers and building owners. OpenEIS is designed as a no-cost/low-cost solution that will propagate the automated fault detection and diagnostic (AFDD) solutions and automated identification of Re-tuning™ (AIRx) measures into the marketplace by providing state-of-the-art analytical and diagnostic algorithms. As OpenEIS penetrates the market, demand by control system manufacturers and integrators serving small and medium commercial customers will help push these types of commercial software tool offerings into the broader marketplace. OpenEIS analytical tools can also help with Re-tuning or retro-commissioning small- and medium-size commercial buildings.

One of the largest obstacles to data analytics (including but not limited to building energy and efficiency related analysis) is overcoming incomplete and non-uniform raw data. Few (if any) tools allow a user to merge data from multiple sources (with possible gaps in the data) and obtain one uniform data set. Due to disparity in data sets, gaps and other problems the efforts required to merge and 'fix' these problems can consume untold hours before the data is usable. OpenEIS overcomes this functionality drawback with multiple aggregation filters for use in merging data, aggregating trend data from high sampling frequency to a lower sampling frequency, and other manipulations to create easily usable data sets that are suitable for immediate value-added analysis.

OpenEIS is compatible with the Green Button data format. The Green Button initiative gives utility customers easy access to their electricity usage data. This data is provided as a text file in a format that is standard across multiple utilities. This data file can then be shared with third party developers who can provide valuable context, analysis, and other functions based on that usage data.

Although OpenEIS was initially developed for building systems, it can easily be extended to include analysis tools for other types of systems and devices (i.e., nearly any device or

system where data is trended). OpenEIS is compatible with most operating systems and can be run on Windows®, Mac®, and Linux® operating systems. OpenEIS can also be deployed in the Cloud. OpenEIS uses standard browser as a user interface. Although it has been tested with all major browsers, Google Chrome is recommended for best results.

The OpenEIS is a standalone tool that was developed to facilitate analysis of data from building (energy and other data). Some key features of OpenEIS include:

1) Importing short-term performance data from loggers,
    a. Automated meters,
    b. Green Button XML,
    c. Data from building automation systems, etc.

2) Merging raw data files from difference sources into datasets,
3) Merging mismatched time stamps,
4) Filling missing data,
5) Time zone correction, etc.

List of OpenEIS applications are listed in the Appendix that follows this overview.

Appendix: OpenEIS Applications

1. Heat Map

1.1. Description

Heat maps are a means of visualizing and presenting the information that is contained in a time series load profile. The maps color-code the size of the load so that hot spots and patterns are easily identified.

1.2. Inputs

Variable Name	Variable Description	Required
WholeBuildingPower	Whole Building Power	True

1.3. Configurable parameters

Variable Name	Variable Description	Required
building_name	Building Name	False

1.4. Output & Graph

- Hourly load for each day in the data set

2. Load Profile

2.1. Description

Time series load profiling is used to understand the relationship between energy use and time of day. Abnormalities or changes in load profiles can indicate inefficiencies due to scheduling errors, unexpected or irregular equipment operation, high use during unoccupied hours, or untimely peaks.

2.2. Inputs

Variable Name	Variable Description	Required
WholeBuildingPower	Whole Building Power	True

2.3. Configurable parameters

Variable Name	Variable Description	Required
building_name	Building Name	False

2.4. Output & Graph

- Daily load profile for all days (5 series: all days, weekdays, Saturdays, Sundays, holidays series)

3. Load Profile Retro-commissioning Rx (M&V)

3.1. Description

Load Profile app for Rx

3.2. Inputs

Variable Name	Variable Description	Required
WholeBuildingPower	Whole Building Power	True

3.3. Configurable parameters

Variable Name	Variable Description	Required
building_name	Building Name	False
Pre-Rx start date	Before Rx start date	True
Pre-Rx end date	Before Rx end date	True
Post-Rx start date	After Rx start date	True
Post-Rx end date	After Rx end date	True

3.4. Output & Graph

- Daily load profile for all days (pre-Rx series and post-Rx series)
- Daily load profile for weekdays (pre-Rx series and post-Rx series)
- Daily load profile for Saturdays (pre-Rx series and post-Rx series)
- Daily load profile for Sundays (pre-Rx series and post-Rx series)
- Daily load profile for holidays (pre-Rx series and post-Rx series)

4. Energy Savings

4.1. Description

Whole-building Energy savings is used to quantify the energy savings associated with an improvement in building operations or equipment. Energy savings is calculated as the difference between the metered energy use after improvements were made, and the baseline projection of energy use.

4.2. Inputs

Variable Name	Variable Description	Required

WholeBuildingPower	Whole Building Power	True
OutdoorAirTemperature	Outdoor Air Temperature	True

4.3. Configurable parameters

Variable Name	Variable Description	Required
building_name	Building Name	False
baseline_startdate	Baseline Start Date (YYYY-MM-DD)	True
baseline_stopdate	Baseline End Date (YYYY-MM-DD)	True
savings_startdate	Savings Start Date (YYYY-MM-DD)	True
savings_stopdate	Savings End Date (YYYY-MM-DD)	True

4.4. Output & Graph

- Energy savings graph: measured and predicted power

5. AHU/RTU Economizer Diagnostics

5.1. Description

Automated fault detection and diagnostics of Economizer System. Diagnostics included in the tool meet California Title 24 requirements:

- Insufficient outdoor air intake
- Excess outdoor air intake
- Economizing when unit should not
- Economizing when unit should
- Temperature sensor fault

5.2. Inputs

Variable Name	Variable Description	Required
SupplyFanStatus	Supply Fan Status	True
OutdoorAirTemperature	Outdoor Air Temperature	True
MixedAirTemperature	Mixed Air Temperature	True
ReturnAirTemperature	Return Air Temperature	True
OutdoorDamperSignal	Outdoor Damper Command	True
CoolingCall	Cooling Call Command	True
SupplyFanSpeed	Supply Fan Speed	False
DischargeAirTemperature	Supply Air Temperature	False
DischargeAirTemperatureSetPoint	Supply Air Temperature set point	False
CoolingCoilValvePosition	Cooling Coil Valve Position	False

5.3. Configurable parameters

Variable Name	Variable Description	Required
data_window	Minimum Elapsed time for analysis in minutes. Default is 30 minutes.	True
open_damper_time	Delay time for steady-state conditions in minutes. Default is 5 minutes	True
no_required_data	Number of required data measurements to perform diagnostic. Default is 20 minutes	True
low_supply_fan_threshold	Value above which the supply fan will be considered at its minimum speed (%). Default is 20%.	True
rated_cfm	Rated CFM of supply fan at 100% speed (CFM). Default value is 1000.	True
mat_low_threshold	Mixed-air temperature sensor low limit (°F). Default is 50.0	True
mat_high_threshold	Mixed-air temperature sensor high limit (°F). Default is 90	True
rat_low_threshold	Return-air temperature sensor low limit (°F). Default is 50.0	True
rat_high_threshold	Return-air temperature sensor high limit (°F). Default is 90	True
oat_low_threshold	Outdoor-air temperature sensor low limit (°F). Default is 30	True
oat_high_threshold	Outdoor-air temperature sensor high limit (°F). Default is 100	True
temp_deadband	Economizer control temperature dead-band (°F). Default is 1	True
minimum_damper_setpoint	Minimum outdoor-air damper set point (%). Default is 15.0	True
excess_damper_threshold	Value above the minimum damper set point at which a fault will be called(%). Default is 20.0	True
econ_hl_temp	High limit (HL) temperature for HL type economizer (°F). Default is 60	True
cooling_enabled_threshold	Amount AHU/RTU chilled water valve must be open to consider unit in cooling mode (%). If device is an RTU, the value is always 1 (cooling_status). If the device is an AHU, default is 5%.	True
insufficient_damper_threshold	Value below the minimum outdoor-air damper set-point at which a fault will be identified (%). Default is 15%.	True
ventilation_oaf_threshold	The value below the desired minimum OA % where a fault will be indicated (%). Default is 5%.	True

desired_oaf	The desired minimum OA percent (%), Default is 10%.	True
excess_oaf_threshold	The value above the desired OA % where a fault will be indicated (%). Default value is 30%	True
economizer_type	Economizer type: <DDB> - differential dry bulb <HL> - High limit. Default value is 'DDB'	True
open_damper_threshold	Threshold in which damper is considered open for economizing (%). Default value is 75%.	True
oaf_economizing_threshold	Value below 100% in which the OA is considered insufficient for economizing (%). Default is 25%.	True
oaf_temperature_threshold	Required difference between OAT and RAT for accurate diagnostic (°F). Default is 5°F	True
device_type	Device type: <RTU> or <AHU> Default value is 'AHU'	True
temp_difference_threshold	Threshold for detecting temperature sensor problems (°F). Default is 4°F.	True
oat_mat_check	Temperature threshold for OAT and MAT consistency check for times when the damper is near 100% open (°F). Default is 5°F	True
temp_damper_threshold	Damper position to check for OAT/MAT consistency (%). Default value is 90%.	True
eer	AHU/RTU rated EER. Default value is 10	True

5.4. Output & Graph

- AHU Economizer Performance Evaluation
- AHU Discharge Cooling and Economizer Performance Analysis
- Seasonal AHU Mixed Air Temperature Response Analysis
- Interactive graph of hourly diagnostics result

6. AHU/RTU Diagnostics

6.1. Description

Provide visualization for AHU/RTU performance.

6.2. Inputs

Variable Name	Variable Description	Required
MixedAirTemperature	Whole Building Power	True
OutdoorAirTemperature	Outdoor Air Temperature	True
ReturnAirTemperature	Return Air Temperature	False
OutdoorDamperSignal	Outdoor damper command	False
OccupancyMode	Occupancy mode	False
DuctStaticPressure	Duct Static Pressure	False
DuctStaticPressureSetPoint	Duct Static Pressure set point	False
SupplyFanSpeed	Supply Fan Speed	False
ReturnFanSpeed	Return Fan Speed	False
SupplyFanStatus	Supply Fan Status	False
CoolingCoilValvePosition	Cooling Coil Valve Position	False
HeatingCoilValvePosition	Heating Coil Valve Position	False
DischargeAirTemperature	Discharge Air Temperature	False
DischargeAirTemperature SetPoint	Discharge Air Temperature set point	False

6.3. Output & Graph

- AHU Economizer Response Analysis
- Seasonal AHU Economizer Damper Command Response Analysis
- AHU Discharge Static Pressure Control Performance Analysis
- AHU VFD-Driven Fan Tracking (Supply and Return) Performance Analysis
- AHU Simultaneous Heating and Cooling Performance Analysis
- AHU Heating and Cooling Coil Performance Analysis
- Discharge Air Temperature Set Point Performance Analysis
- Discharge Air Temperature Control Performance Analysis
- AHU Operational Day, Night and Weekend Operations Analysis

7. AIRx: AHU Static Pressure

7.1. Description

Analysis of AHU data to identify opportunities with static pressure control, including opportunity for reset. Diagnostics implemented:

- No static pressure reset
- High duct static pressure
- Low duct static pressure
- Duct static pressure control performance

7.2. Inputs

Variable Name	Variable Description	Required

SupplyFanStatus	Supply Fan Status	True
TerminalBoxDamperCommand	All Terminal Box Damper Command	True
DuctStaticPressure	Duct Static Pressure	True
DuctStaticPressureSetPoint	Duct Static Pressure set point	True
SupplyFanSpeed	Supply Fan Speed	False

7.3. Configurable parameters

Variable Name	Variable Description	Required
data_window	Minimum Elapsed time for analysis (minutes). Default is 15.	True
no_required_data	Number of required data measurements to perform diagnostic. Default is 30	True
low_supply_fan_threshold	Value above which the supply fan will considered at its minimum speed (%). Default is 20	True
warm_up_time	When the system starts this much time will be allowed to elapse before adding using data for analysis (minutes). Default is 30	True
zone_high_damper_threshold	Zone high damper threshold used for detection of duct static pressure problems (%). Default is 90.	True
zone_low_damper_threshold	Zone low damper threshold used for detection of duct static pressure problems (%). Default is 10	True
max_duct_stp_stpt	Maximum duct static pressure set point allowed, when auto-correction is enabled, i.e., the set point chosen by the diagnostic will never exceed this value (inch w.g.). Default is 2.5	True
duct_stc_retuning	Increment/decrement of static pressure set point during auto-correction (inch w.g.). Default is 0.15	True
min_duct_stp_stpt	Minimum duct static pressure set point allowed, when auto-correction is enabled, i.e., the set point chosen by the diagnostic will never exceed this value (inch w.g.). Default is 0.25	True
hdzone_damper_threshold	Threshold for zone damper. If the average value of the zone dampers is less than this threshold the fan is	True

	supplying too much air (%). Default is 30.	
setpoint_allowable_deviation	Allowable deviation from set points before a fault message is generated (%). Default is 10	True
stpr_reset_threshold	Required difference between minimum and maximum duct static pressure set point detecting a duct static pressure set point reset (inch w.g.). Default is 0.25	True

7.4. Output & Graph

- Interactive graph of hourly diagnostics result

8. AIRx: AHU Supply Temperature

8.1. Description

Analysis of AHU data to identify opportunities with supply temperature control, including opportunity for reset. Diagnostics implemented:

- No supply air temperature reset
- High supply air temperature
- Low supply air temperature
- Supply air temperature control performance

8.2. Inputs

Variable Name	Variable Description	Required
SupplyFanStatus	Supply Fan Status	True
TerminalBoxReheatValvePosition	All terminal-box re-heat valve commands	True
TerminalBoxDamperCommand	All terminal-box damper commands	True
DischargeAirTemperature	AHU supply-air (discharge-air) temperature	True
DischargeAirTemperatureSetPoint	Supply-air temperature set-point	True
SupplyFanSpeed	Supply Fan Speed	False

8.3. Configurable parameters

Variable Name	Variable Description	Required
data_window	Minimum Elapsed time for analysis (minutes). Default is 15.	True
no_required_data	Number of required data	True

	measurements to perform diagnostic. Default is 30	
warm_up_time	When the system starts this much time will be allowed to elapse before adding using data for analysis (minutes). Default is 30	True
low_supply_fan_threshold	Value above which the supply fan will be considered at its minimum speed (%). Default is 20	True
high_supply_fan_threshold	Zone low damper threshold used for detection of duct static pressure problems (%). Default is 10	True
setpoint_allowable_deviation	Allowable deviation from set points before a fault message is generated (%). Default is 10	True
reheat_valve_threshold	Zone re-heat valve threshold for SAT RCx, compared to average zone re-heat valve (%). Default is 50	True
percent_reheat_threshold	Threshold for average percent of zones where terminal box re-heat is ON (%). Default is 25	True
maximum_sat_stpt	Maximum SAT set point allowed when auto-correction is enabled, i.e., the set point chosen by the diagnostic will never exceed this value ({drg}F). Default is 75.	True
rht_on_threshold	Value above which zone re-heat is considered ON (%). Default is 10	True
sat_retuning	Decrement of supply-air temperature set point during auto-correction ({drg}F). Default is 1.0	True
sat_high_damper_threshold	High zone damper threshold for high supply-air temperature auto-correct RCx (%). Default is 30	True
percent_damper_threshold	Threshold for the average % of zone dampers above high damper threshold (%). Default is 50.	True
minimum_sat_stpt	Maximum supply-air temperature set point allowed, when auto-correction is enabled, i.e., the set point chosen by the diagnostic will never exceed this value ({drg}F). Default is 50	True
sat_reset_threshold	Threshold difference required to detect a supply-air temperature set point reset ({drg}F). Default is 3	True

8.4. Output & Graph

- Interactive graph of hourly diagnostics result

9. AIRx: AHU Operation Schedule

9.1. Description

Analysis of AHU data to identify AHU schedule problems.

9.2. Inputs

Variable Name	Variable Description	Required
SupplyFanStatus	Supply Fan Status	True
DuctStaticPressure	Duct static pressure	True
SupplyFanSpeed	Supply Fan Speed	False

9.3. Configurable parameters

Variable Name	Variable Description	Required
data_window	Minimum Elapsed time for analysis (minutes). Default is 15.	True
no_required_data	Number of required data measurements to perform diagnostic	True
low_supply_fan_threshold	Value above which the supply fan will be considered at its minimum speed (%). Default is 20	True
unocc_time_threshold	Time threshold used for AHU schedule Dx (%). Default is 30	
unocc_stp_threshold	AHU off static pressure dead-band. Detects whether the duct static pressure exceeds this value during non-working scheduled hours (inch w.g.). Default is 0.2	True
monday_sch	Monday AHU occupied schedule, Used to detect the time when the supply fan should be operational). Default is '6:30;18:30'	True
tuesday_sch	Monday AHU occupied schedule, Used to detect the time when the supply fan should be operational). Default is '6:30;18:30'	True
wednesday_sch	Tuesday AHU occupied schedule, Used to detect the time when the supply fan should be operational). Default is '6:30;18:30'	True

thursday_sch	Thursday AHU occupied schedule, Used to detect the time when the supply fan should be operational). Default is '6:30;18:30'	True
friday_sch	Friday AHU occupied schedule, Used to detect the time when the supply fan should be operational). Default is '6:30;18:30'	True
saturday_sch	Saturday AHU occupied schedule, Used to detect the time when the supply fan should be operational). Default is '0:00;0:00'	True
sunday_sch	Sunday AHU occupied schedule, Used to detect the time when the supply fan should be operational). Default is '0:00;0:00'	True
holiday_sch	Holiday AHU occupied schedule, Used to detect the time when the supply fan should be operational). Default is '0:00;0:00'	True

9.4. Output & Graph

- Interactive graph of hourly diagnostics result

10. AIRx: Hot Water Distribution System Diagnostics

10.1. Description

Analysis of hot water distribution data to identify opportunities with hot water distribution systems.

10.2. Inputs

Variable Name	Variable Description	Required
LoopDifferentialPressure	Hot water central plant loop differential pressure	False
LoopDifferentialPressureSetPoint	Hot water central plant loop differential pressure set point	False
PumpStatus	Hot water central plant pump status	False
BoilerStatus	Hot water central plant boiler status	False
PumpVFDCommand	Hot water central plant pump VFD commands	False
SupplyWaterTemperature	Hot water central plant	True

	supply water temperature	
SupplyWaterTemperatureSetPoint	Hot water central plant supply water temperature set point	False
ReturnWaterTemperature	Hot water central plant return water temperature	False
OutdoorAirTemperature	Outdoor Air Temperature	False

10.3. Output & Graph

- Hot Water Plant Set Point Performance Analysis
- Hot Water Plant Loop Differential Pressure Set Point Performance Analysis
- Seasonal Hot Water Temperature Response Analysis

11. AIRx: Hot Water Distribution System

11.1. Description

Automated fault detection and diagnostics of hot water distribution system.
Diagnostics implemented:

- Hot water loop low delta T
- Hot water loop supply temperature reset
- Hot water high supply temperature
- Hot water differential pressure reset
- Hot water high differential pressure
- Hot water supply temperature control loop
- Hot water pressure control loop

11.2. Inputs

Variable Name	Variable Description	Required
LoopDifferentialPressure	Hot water central plant loop differential pressure	True
LoopDifferentialPressureSetPoint	Hot water central plant loop differential pressure set point	True
PumpStatus	Hot water central plant pump status	False
BoilerStatus	Hot water central plant boiler status	True
PumpVFDCommand	Hot water central plant pump VFD commands	True
SupplyWaterTemperature	Hot water central plant supply water temperature	True
SupplyWaterTemperatureSetPoint	Hot water central plant	True

	supply water temperature set point	
ReturnWaterTemperature	Hot water central plant return water temperature	True

11.3. Configurable parameters

Variable Name	Variable Description	Required
data_window	Minimum Elapsed time for analysis (minutes). Default is 180.	True
no_required_data	Number of required data measurements to perform diagnostic. Default is 30	True
warm_up_time	When the system starts this much time will be allowed to elapse before adding using data for analysis (minutes). Default is 30	True
setpoint_allowable_deviation	Percent allowable deviation from set points (HWS and loop DP (%). Default is 10	True
min_dp_threshold	Hot water loop minimum operational differential pressure (psi)	True
max_dp_threshold	Hot water loop maximum operational differential pressure (psi). Default is 50	True
dp_pump_threshold	Pump threshold to determine if the loop DP is too high (%). Default is 45	True
dp_reset_threshold	HW loop DP threshold to detect DP reset (psi). Default is 5	True
hwst_reset_threshold	HW supply temperature threshold to detect HW supply temperature reset ({drg}F). Default is 10	True
hw_st_threshold	HW supply temperature threshold to detect if the HW supply temperature is too high ({drg}F). Default is 120	True
hw_pump_vfd_threshold	HW loop pump VFD command threshold used to determine if the HW supply temperature is too high (%). Default is 25	True
min_hwst_threshold	Minimum allowable operational HW supply temperature ({drg}F). Default is 125	True
max_hwst_threshold	Maximum allowable operational HW supply temperature ({drg}F). Default is 190	True
min_hwrt_threshold	Minimum allowable operational HW return temperature ({drg}F). Default is 115	True

max_hwrt_threshold	Maximum allowable operational HW return temperature ({drg}F). Default is 180	True
desired_delta_t	Desired delta-T (difference between HWS and HWR temperatures ({drg}F). Default is 20	True
delta_t_threshold	Band around desired delta-T where where delat-T is considered OK ({drg}F). Default is 10	True

11.4. Output & Graph

- Interactive graph of hourly diagnostics result

12. AIRx: AHU-VAV Zone Diagnostics

12.1. Description

Analysis of AHU variable-air-volume zone data to identify opportunities.

12.2. Inputs

Variable Name	Variable Description	Required
ZoneTemperature	Whole Building Power	True
TerminalBoxDamperCommand	Outdoor Air Temperature	False
ZoneTemperatureSetPoint	Zone Temperature set point	False
TerminalBoxReheatValvePosition	Terminal box reheat valve position	False
TerminalBoxFanAirflow	Terminal box fan air flow	False
OccupancyMode	Occupancy mode	False

12.3. Output & Graph

Zone Terminal-Box Performance Analysis: a time-series plot of zone temperature, zone temperature set point, outdoor air temperature, terminal-box reheat valve position, terminal-box fan airflow, and occupancy mode.

13. AIRx: Temperature Set Point Detector

13.1. Description

Detect temperature set point based on zone temperature.

13.2. Inputs

Variable Name	Variable Description	Required
ZoneTemperature	Zone Temperature	True

SupplyFanStatus	Supply Fan Status	False

13.3. Configurable parameters

Variable Name	Variable Description	Required
minimum_data_count	Minimum number of records needed for the app to run. Default is 5 records	True
area_distribution_threshold	Area distribution threshold. Default is 0.1	True

13.4. Output & Graph

Zone Terminal Box Performance Analysis plot includes detected set point, zone temperature, and supply fan status series

14. AIRx: Compressor Cycling Detection

14.1. Description

Detect compressor-cycling issues based on zone temperature.

14.2. Inputs

Variable Name	Variable Description	Required
ZoneTemperature	Zone Temperature	True
CompressorStatus	Compressor Status	False

14.3. Configurable parameters

Variable Name	Variable Description	Required
minimum_data_count	Minimum number of records needed for the app to run. Default is 5 records	True

14.4. Output & Graph

A plot of detected cycling, zone temperature, and compressor status if available

15. AIRx: Schedule Detector

15.1. Description

Detect operational schedule of HVAC system based on zone temperature.

15.2. Inputs

Variable Name	Variable Description	Required
ZoneTemperature	Zone Temperature	True

15.3. Configurable parameters

Variable Name	Variable Description	Required
sample_rate	Sample rate for occupancy schedule detection (min). Default is 60Min.	True

15.4. Output & Graph

A plot of detected operational schedule