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Updating a building automation system (BAS) for optimized heat pump performance

Michel Parent, Technosim

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Agenda

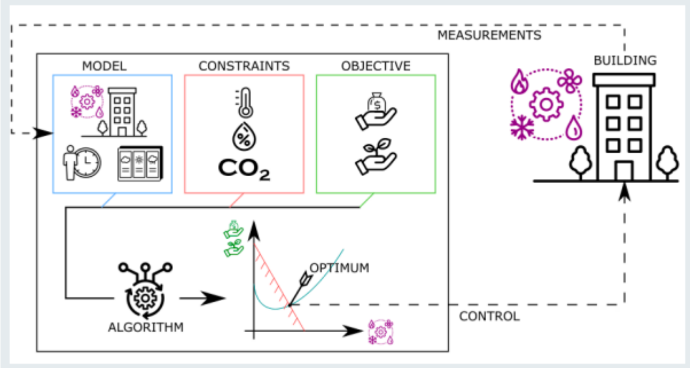
- Introduction
- Sensor and BAS data infrastructure
- BAS control strategies to optimize heat pump performance
- Fault detection and data monitoring
- Questions and answers (Q&A)

Objectives

1. Understand the importance of BAS integration for heat pumps
2. Identify control strategies to improve heat pump operation
3. Evaluate impacts of effective scheduling, optimized setpoints and enhanced BAS control logic on system performance
4. Understand the role of FDD for proper heat pump operations

BAS and heat pumps

- Adapting a BAS to integrate heat pumps primarily involves ensuring **compatibility**, implementing **advanced control strategies** as well as optimizing for **energy efficiency** and **demand flexibility**. This process consists of moving beyond simple on/off commands to a more sophisticated, data-driven approach.
- Heat pumps are sophisticated machines, and proper integration into a BAS is essential for optimal performance.



Types of heat pump

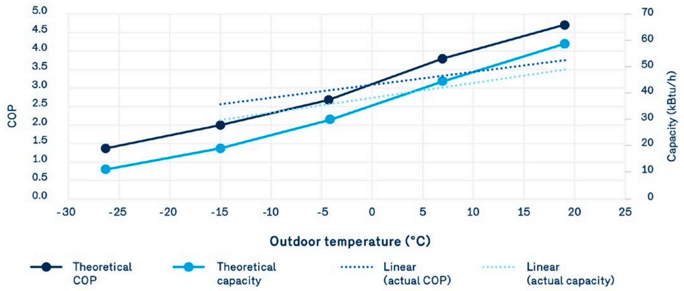
Performance optimization varies depending on the type of heat pump installed in a building:

1. **Air-to-air heat pumps** extract heat from ambient outdoor air and transfer it to indoor air for heating.
2. **Air-to-water heat pumps** extract heat from ambient outdoor air and transfer it to a hydronic loop.
3. **Water-to-water heat pumps** extract heat from a water source (e.g. geothermal, heat recovery unit) and transfer it to a hydronic loop.
4. **Water-to-air heat pumps** (i.e. distributed water-source heat pumps) extract heat from the main hydronic loop and utilize air for space heating.

Heat recovery chillers are not considered heat pumps as they do not have a reversing valve. Of note, some heat pumps may just operate in heating mode due to design considerations, rendering the reversing valve irrelevant.

Air-to-air heat pumps and rooftop units

- Packaged heat pumps - very common in smaller commercial applications:
  - Capacity and coefficient of performance (COP) vary with outdoor air temperature (OAT).
  - Modern systems can operate to low OAT (e.g. -15 ^{o}C).
  - They are almost always associated with a supplemental heating source.
- Mini-split heat pumps
  - They can be very efficient, even at low OAT.
  - Controls can be problematic with existing heating.



https://informatech.energir.com/

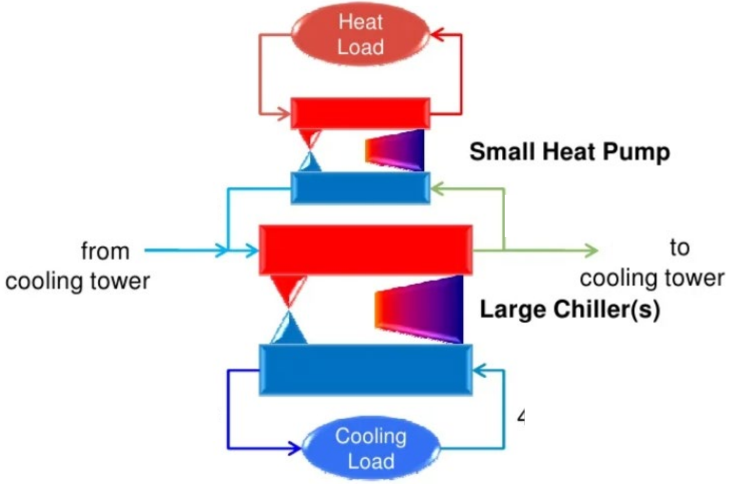
Central air-source hydronic heat pumps
(air-to-water)

- A heat pump system that provides heating through hot water/glycol
- Can be installed in existing boiler plant to replace or supplement existing boilers
- Does not always replace existing cooling system
- Always verify the ambient temperature range and supply temperature range
- Provide either cooling or heating, not both at the same time

Hot Water Delivery Temp °C	Nominal Ambient Operating Temperature - °C (Minimum)	
	Refrigerant Listed	
	R410 A	R407C
60	8	14
54	4	11
49	1	7
43	-3	3
38	-9	-1
32	-16	-7
27	-20	-10

Cascade heat pumps (typically water-to-water)

- Chillers or heat recovery chillers may not provide the temperature levels needed.
- For medium temperature loops, the use of a heat pump to boost the condenser water temperature can be considered.
- A secondary heat pump uses the condenser water from the main chiller to produce even warmer hot water.



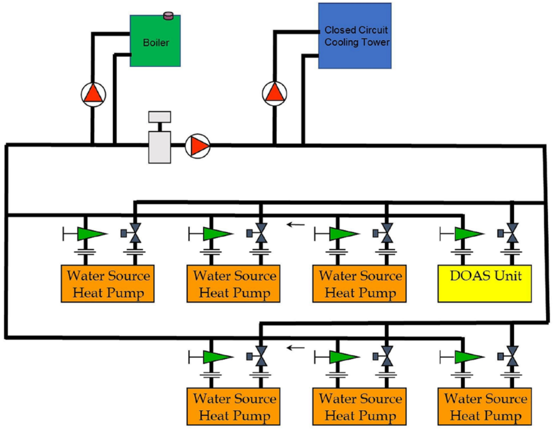
Cascade arrangement

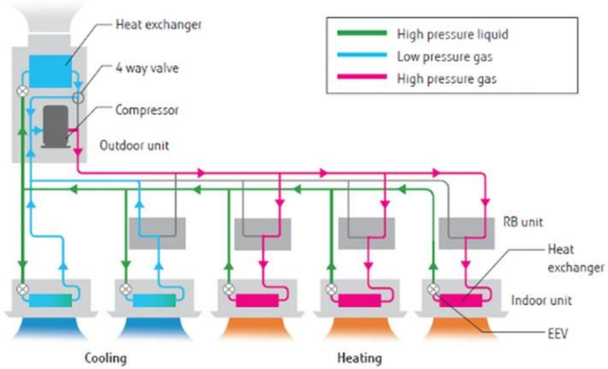
Central ground-source heat pumps (GSHPs)
(can be water-to-water or water-to-air)

- These are very high-efficiency systems when well designed and controlled.
- A central heat pump, similarly to a chiller, is installed and provides hydronic heating in winter and chiller water in summer.
- The ground heat exchanger is usually composed of a series of vertical wells but can be horizontal trenches for smaller buildings or even open wells.
- Supplemental heating is required to optimize the cost of the ground exchanger.

Distributed heat pumps (often water-to-air)

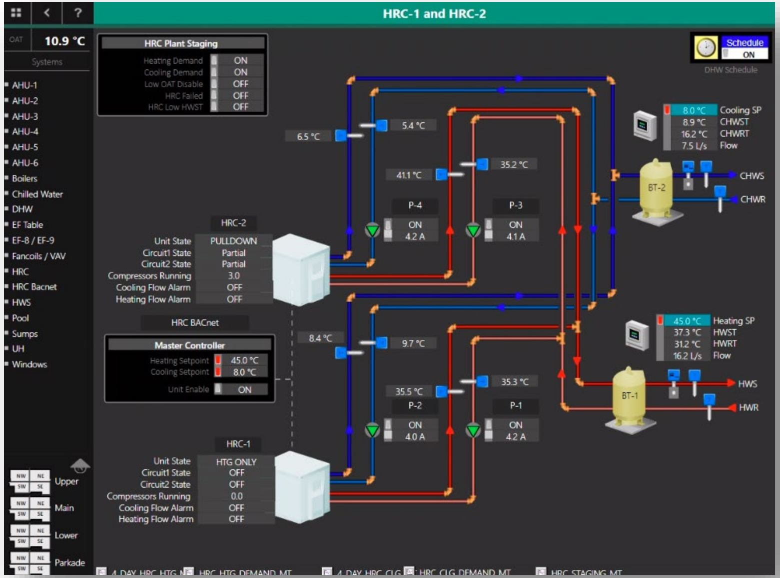
- Water-loop heat pumps (WLHPs): heat pumps located throughout the building:
  - Can be ground-source, air-source or boiler supplemented, with cooling tower
  - Capital-intensive in a retrofit case
- Variable refrigerant flow (VRF) systems
  - Two types: heat recovery and heat pump, heat recovery can also have a water-loop configuration; the heat recovery configuration is still a heat pump.
  - Typically, air-to-air





Four-pipe heat pump (air-to-water)

- Produce both hot water and chilled water through two distinct hydronic loops
- Can recover heat from the cooling loop to use for heating
- Use outdoor air as source/sink for either heating or cooling
- Can produce hot water typically up to 60 °C and operate down to -15 °C



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Heat pump implementation considerations

1. **Electrical capacity**
   - Electrical load review required
   - If you have air conditioning already, might not be an issue

2. **Supply water temperature**
   - Typical air-source heat pumps (ASHPs) have a maximum supply water temperature of 30-40 °C.
   - If your hydronic system is designed for high temperature (i.e. 70-80°C), retrofit of terminal units to low-temperature may be required.

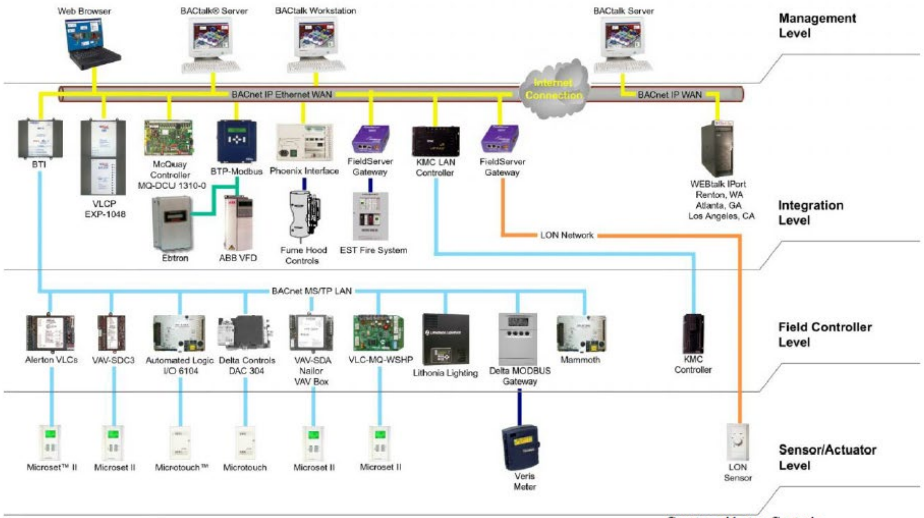
Sensor and BAS data infrastructure

Integrating heat pumps into your BAS

Typical BAS structure ⟹

- Your heat pump on-board controller should be BACnet compliant
  - E.g. AAC (advanced application controller)
- Allows easier integration into most BAS
- Greater optimization opportunities

Four Level Architecture



Courtesy Alerton Controls

Integration with a BAS

- Do not let your heat pump be an isolated island!
  - Integration into a BAS, when present, is a must for optimal operation.
- Most large heat pumps can be integrated in the same way as chillers:
  - Ensure your model is BACnet compliant.
- Older VRF systems often could not be integrated, but newer systems can and should be, sometimes requiring a “gateway”.
- For rooftop units (RTUs), on-board controllers offer some functionalities, but integration is highly preferable. BACnet compatibility is again a key benefit.

BAS points for heat pumps

What key data points should be collected from heat pumps?

Very similar to those of other vapour compression systems and can include:

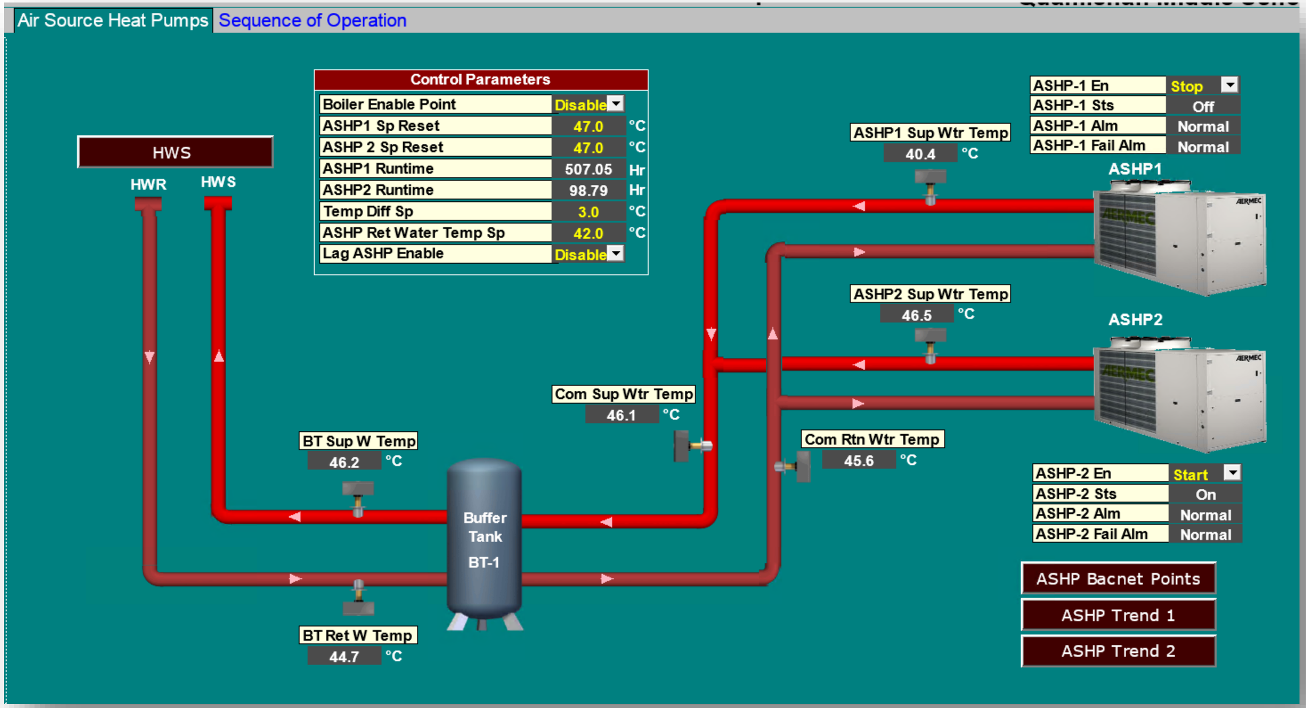
Enable/disable unit: remote on/off system control
System status/mode: monitor the current operating mode (e.g. heating, cooling, defrost, emergency heat, fan only)
Fan operation: start/stop and status monitoring of supply/return fans
Temperature readings:

- Outdoor air dry bulb temperature
- Return air temperature (indoor ambient)
- Supply air temperature (useful for rate-based staging of auxiliary heat)
- Mixed air temperature (for ducted systems)

Auxiliary heat: status, on/off control, switch over and/or transition parameters
Building demand (kW)
Alarms and faults:

Fan failure/status alarms
High/low pressure faults
Smoke detection shutdown/alarm
Defrost cycle indication

Example: air-to-water heat pump



Common BACnet Point Categories

Control & Setpoints:

- Heating_SP, Cooling_SP, Unoccupied_SP (Writable for BAS override)
- Occupancy_Status (Occupied, Unoccupied, Bypass)
- Mode_Command (Heat, Cool, Auto, Off)

Status & Alarms (Read-Only):

- Unit_Status (Running, Fault, Standby, Lockout)
- Compressor_Status (On/Off, Stage)
- Fan_Status (On/Off, Speed)
- Fault_Code (Specific error reporting)

Inputs (Read-Only/Writable):

- Zone_Temperature, Supply_Air_Temperature, Outdoor_Air_Temperature (OAT)
- CO2_Level, Humidity_Level (if equipped)
- Occupancy_Input (from external sensor)

Outputs (Control Signals):

- Compressor_Command (Binary/Analog)
- Fan_Command (Binary/Analog)
- Aux_Heat_Command (Binary/Analog)

Performance & Energy (Read-Only):

- Energy_Meter, Power_Consumption, COP (Coefficient of Performance)
- Balance_Point (Calculated/Reported temperature)

BAS control strategies to optimize heat pump performance

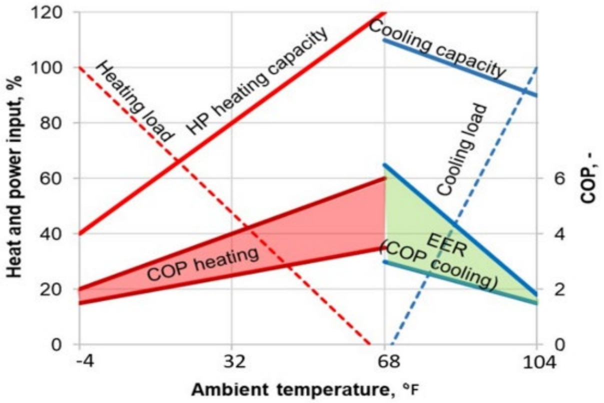
Heat pump control optimization

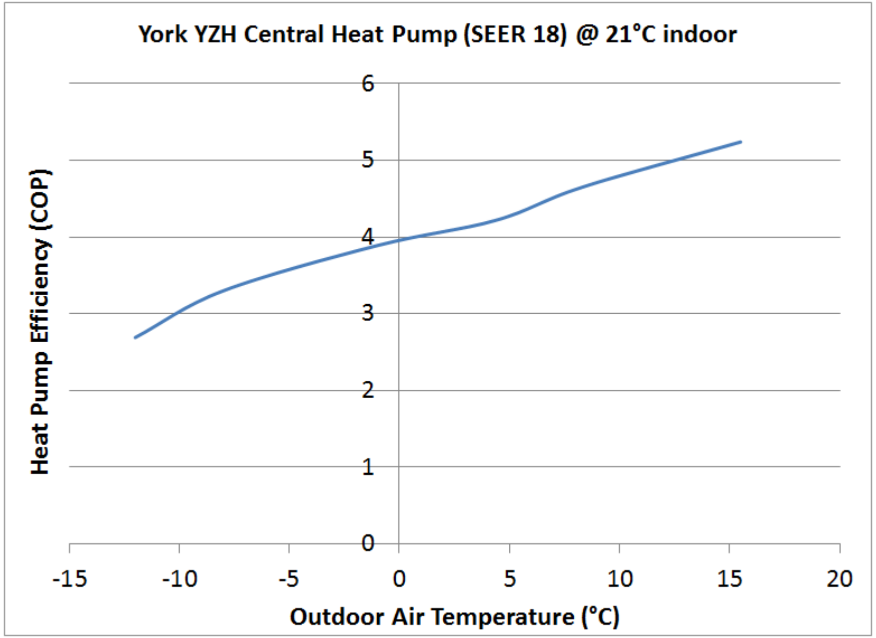
Heat pump performance can be drastically impacted by control strategies and to a greater extent than boilers and chillers. Some key elements to know when adapting your control strategies:

- Operating range of the heat pump, including supply temperature and outdoor temperature (air-source), part-load performance
- Type of supplemental heat and efficiency
- Rate structure, for both energy and demand (separately)
- Your electricity demand profile
- Required supply temperature for heating as a function of outdoor temperature – not guesswork but tested!
- Your goals…cost reduction, GHG reduction, lowest cost increase for a target GHG reduction, etc.

Example: ASHP operating range versus OAT

Performance drops with a decrease in outdoor air temperature; capacity also drops.



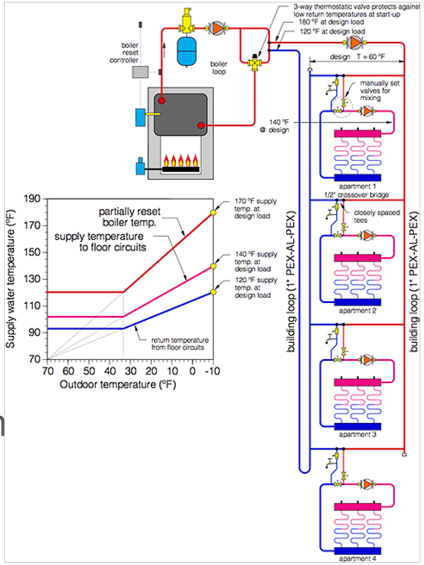


Step 1 in achieving better performance

1. Reduce the loads!
   - Heat pumps are almost always capacity constrained. To get the most out of your system, ensure loads are minimized – not all BAS related:
     - For ventilation systems, reduce airflow to the minimum required (demand control ventilation)
     - Avoid excessively high supply temperature settings (use demand reset rather than simple outdoor reset)
     - Look at simple building envelope improvements (e.g. reducing infiltration and stack effect)
     - Optimal space heating and cooling set point with no simultaneous heating and cooling!

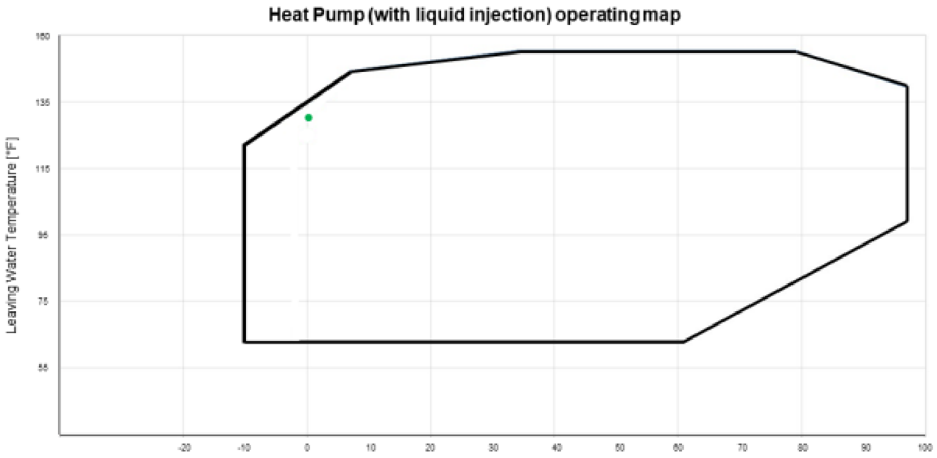
Step 2 – Actual building needs

- Heat pumps are more efficient at lower heating supply temperatures.
- For hydronic systems or multizone air-based heating, establish the required supply temperature based on tests – how low can you go:
  - For a cold day, modulate the supply temperature to establish the minimum needed to still meet the load
  - Repeat for different OATs if you plan to use outdoor reset
  - If you can use demand reset, similar procedure using Trim & Respond
- The test can be done with a boiler or conventional heating source



Know your heat pump temperature limits

- Once you optimized your supply temperature to meet your loads, compare it to what the heat pump can provide.
- This will determine when the heat pump will be disabled or supplemented.



Step 3 – optimize heat pump use versus supplemental

- The goal is to maximize heat pump operating periods with respect to your objectives (GHG, cost).
- Common approaches for establishing the sequencing:
  - Peak demand: for cost optimization purposes, heat pump operates in priority until a given peak is achieved or whenever heat pump capacity is insufficient. Sequence is not directly linked to OAT.
  - Outdoor temperature (air-source): whenever a given OAT is reached, the heat pump stops and supplemental heating takes over, the simplest method. In some systems, supplemental and heat pump can operate at the same time:
    - OAT threshold is based on manufacturer specifications or performance testing when COP and/or capacity drops below a specific value.
  - Maximum GHG: heat pump operates in priority regardless of demand and until OAT (air-source) disables the unit even if a cost penalty is incurred.

Managing supplemental heating

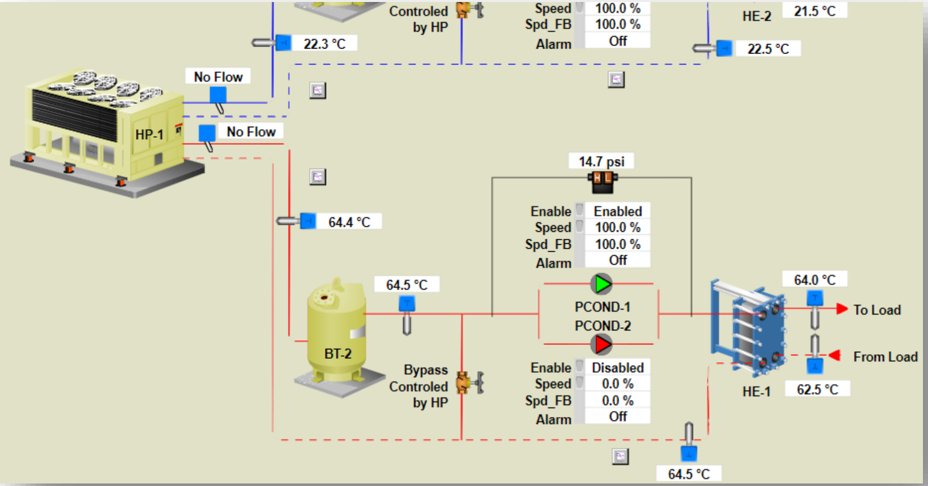
- Supplemental heating is often required and can improve heat pump economics and operation:
  - Air-source heat pumps use either central supplemental heating such as gas-fired RTUs, gas boilers or electric coils.
  - Perimeter heating often plays the role of supplemental heating, such as for mini-split heat pumps, but also for some RTUs.
  - Proper control of supplemental heating is critical to efficient and economical system operation.

Optimal hybrid heating operation

- Typically – gas supplemental and heat pump systems are enabled
- The heat pump operates as lead until building demand reaches a pre-defined value:
  - This value is typically optimized on a monthly basis to minimize overall utility costs, eventually also for global adjustment (GA).
- Need to track demand in real time from a BAS that manages equipment operation based on demand.
- Return temperature must remain within the required range for the heat pump for hydronic systems

Example: Hydronic hybrid operation with high supply temperature

- Supplemental boilers set for 70 oC supply, resulting in 65 oC return
- Heat pumps tripped due to high return
- Need to optimize boiler supply reset strategy

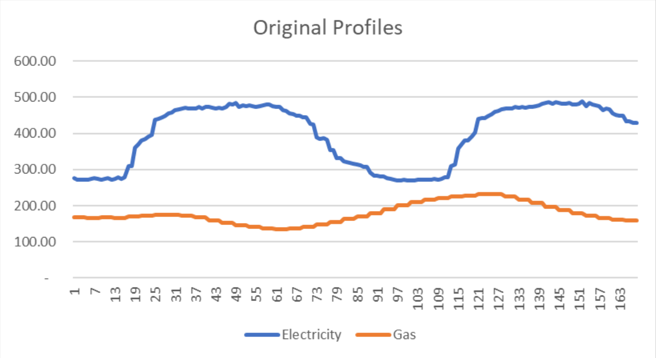


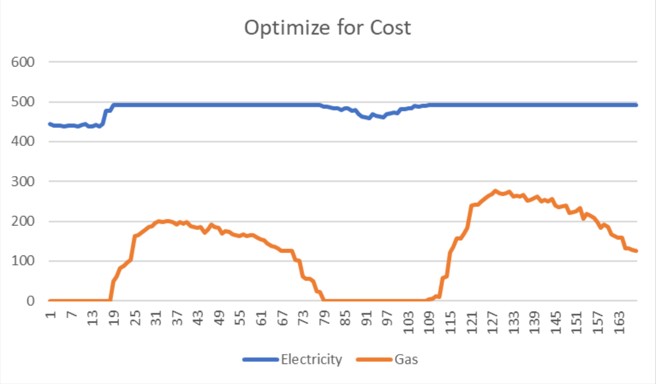
Example of hybrid plant operation

- Electricity profile shows numerous valleys.
- A hybrid pant could allow filling those valleys by using a heat pump with no increase in monthly (invoiceable) demand.

Class	%	Value
GHG reduction	38%	454 tonnes
Gas reduction	66%	276,000 m3
Electricity increase	15%	2,160,000 kWh
Cost **reduction** - Class A	-	**$45,900**
Cost **increase** - Class B	-	**$148,000**

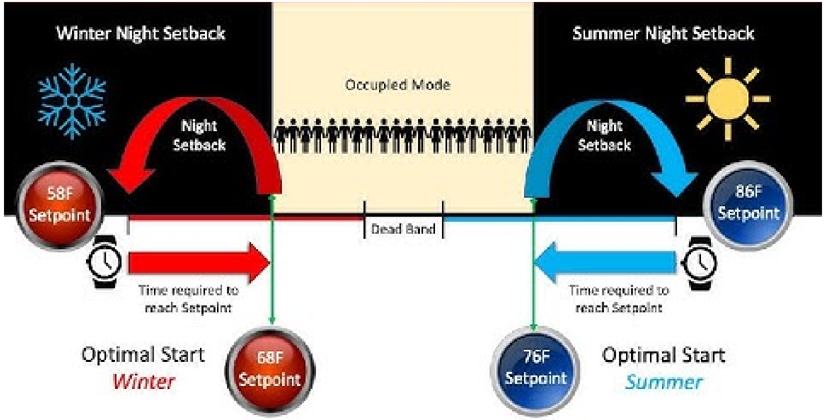
Using $0.40/m3 for gas, marginal cost of energy of $0.03/kWh for Class A and $0.12/kWh for Class B





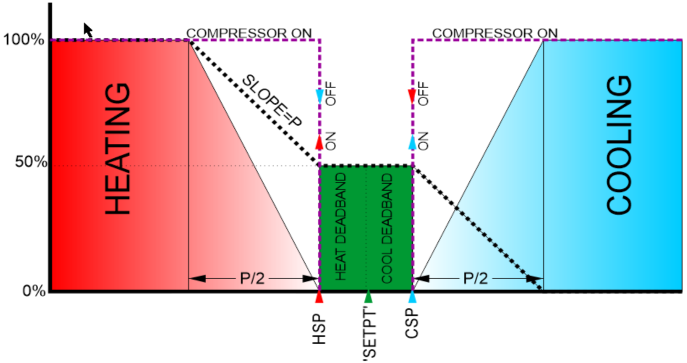
Step 4 – optimize controls

- Heat pumps typically have lower capacity, and warm-up periods are impacted:
  - The set back should still be used, but the required warm-up periods must de established through testing as a function of OAT.
  - Optimal start us done with no ventilation air.
  - Electric demand must be considered during warm-up periods to avoid creating a peak that would negate set back energy cost savings.
  - There can be a point where set back should not be used either due to capacity constraints or peak demand impacts.



Step 4 – optimize controls

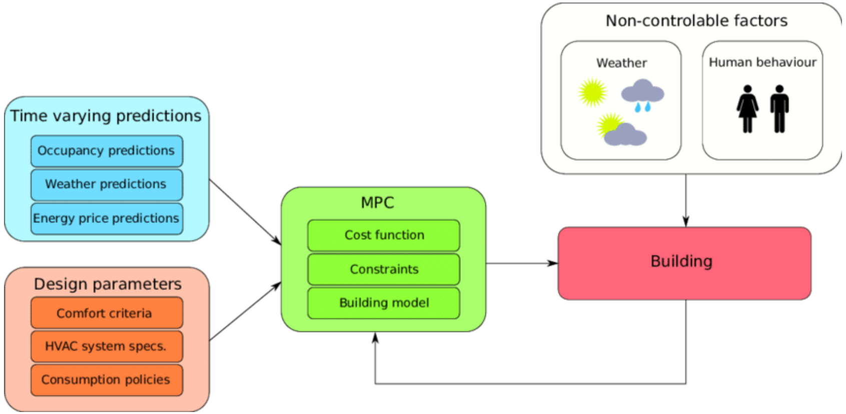
- Space setpoints and dead bands
  - Unless cooling is locked out in winter and heating in summer, there is often a risk of cycling between modes for some heat pumps.
  - Ideally, define separate heating and cooling setpoints with about 2 ºC (adjustable) between the two. Alternatively, cooling and heating modes are defined based on OAT or time of year and lock out cooling/heating to avoid cycling.
  - Each setpoint must have a dead band to avoid cycling the compressor for zone-level heat pumps or single-zone heat pumps.
  - For adjacent zones in open areas, setpoints must be similar to avoid simultaneous heating and cooling if modes are not locked based on OAT or time of year.



Going further - model predictive control (MPC)

Model-based predictive controls use energy consumption trends and expected changes in environmental conditions and occupancy levels to adapt and optimize heat pump operation:

- Optimal control of heat pump based on performance (GHG, cost)
- Considers part-load performance, energy rates, capacity, etc., to sequence heat pumps and any supplemental heating
- Can be used to manage peak demand impact



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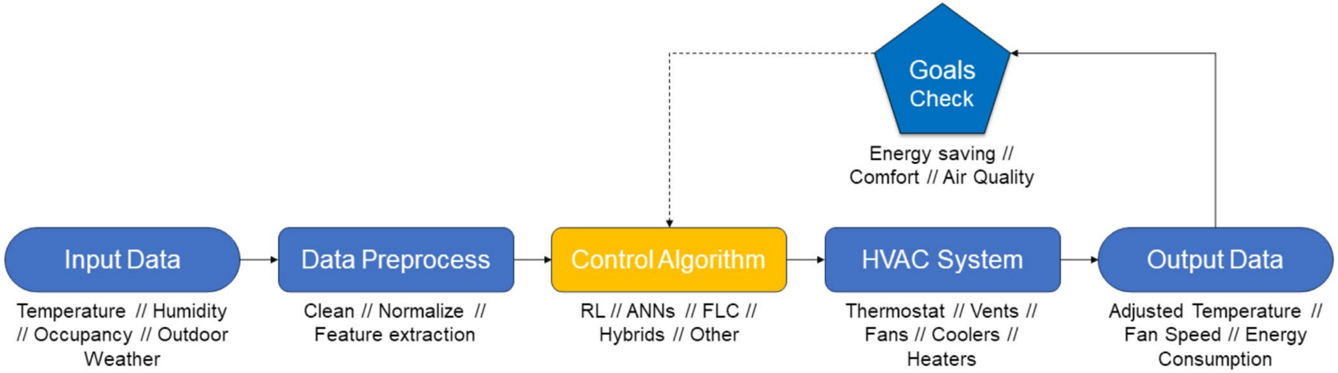
Model-free control (MFC)

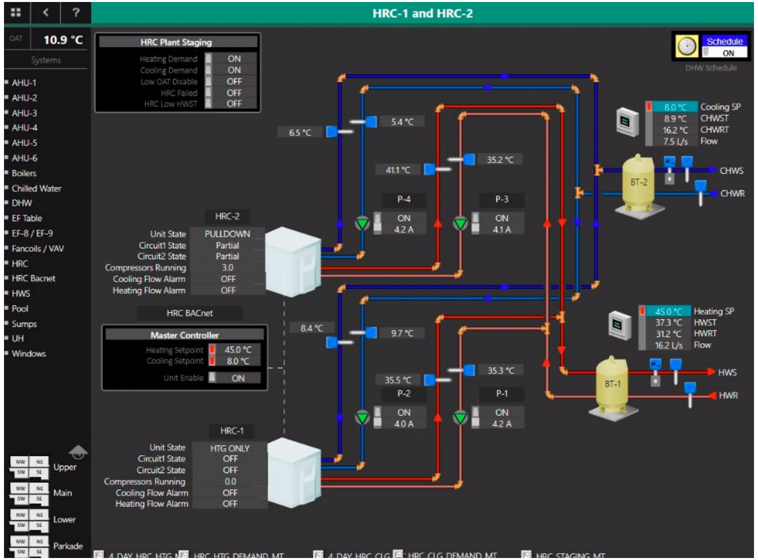
Model-free control leverages data analytics and AI-driven forecasting to enable proactive system adjustments to optimize system performance system based on upcoming weather, occupancy, etc.

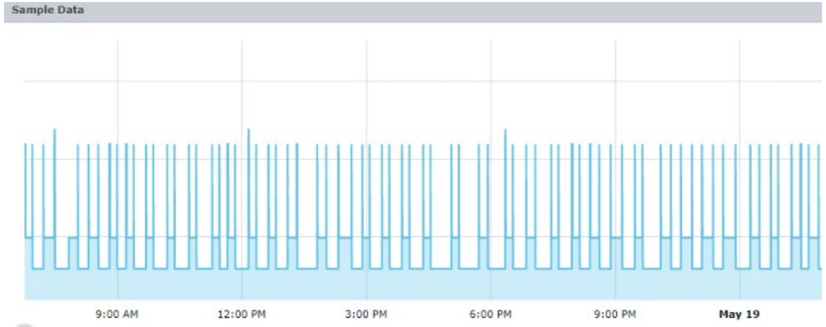


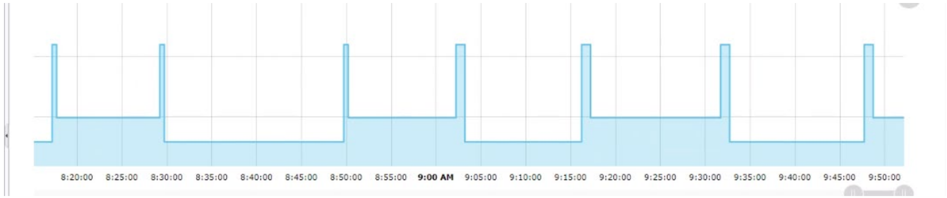
Model-Free HVAC Control in Buildings: A Review, Energies 2023, 16(20), 7124

The risk of poor control

- Heat pumps can have multiple operation modes. Without a proper dead band, short cycling can occur with large energy penalties!







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Fault detection and data monitoring

Defining fault detection and diagnosis (FDD)

The purpose of an FDD algorithm is twofold:

1. Fault detection to determine whether building equipment and systems are operating improperly.
2. Fault diagnosis, in the case of abnormal or improper operation, to isolate the root cause.

FDD is aimed at providing proactive maintenance and repairs, essentially detecting faults before they become major issues and diagnosing the cause(s) of those faults.

FDD basics

How FDD works

Data collection: Sensors gather real-time data (temperatures, pressures, flow rates, power usages) from various points in the heat pump.

Algorithm analysis: FDD software is used to compare actual performance against ideal models or learned patterns.

Fault detection is used to identify deviations such as incorrect refrigerant charges, dirty coils or fan issues.

Diagnosis serves to pinpoint the likely cause (e.g. low superheat indicates undercharged system).

Reporting: Serves to alert building staff with actionable insights via dashboards or alerts.

FDD points for heat pumps

Good FDD can require more BAS data points, for example:

- Evaporator exit saturation temperature
- Evaporator exit superheat
- Compressor discharge temperature
- Condenser inlet saturation temperature
- Liquid line subcooling
- Condenser air temperature rise
- Evaporator air temperature drop
- Liquid line temperature drop

Example of faults for ASHP

Cooling	Heating
Under/Over Charge	Under/Over Charge
Improper Airflow through HXs	Improper Airflow through HXs
Liquid Line Restriction	Liquid Line Restriction
Compressor/Reversing Valve Leakage	Compressor/Reversing Valve Leakage
Non-condensables	

Diagnostics with FDD

- FDD must be adapted to the type of heat pump in your building.
- Most FDDs use rule-based diagnostics.
- Diagnostic rules must be customized for your data points.

Example of heating mode diagnostics for ASHP

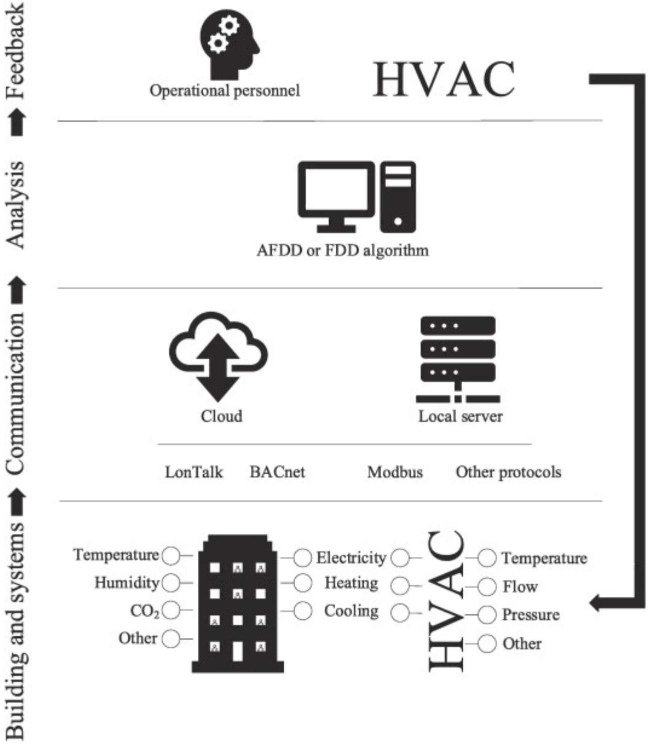
Fault Type	Evap. Temp.	Super heat	Compr. Disch.	Cond. Temp.	Sub-cooling	Cond. Delta-T	Evap. Delta-T
Compressor fault	- ↑	-	-	↓	-	- ↓	-
Condenser fouling	-	-	↑	- ↑	-	↑	-
Evaporator fouling	↓	↑	↑ - ↓	- ↓	-	- ↓	-
Liquid line restriction	-	-	-	-	-	-	-
Refrigerant overcharge	-	-	↑	↑	↑	-	-
Refrigerant undercharge	- ↓	-	-	- ↓	↓	- ↓	-
No fault	-	-	-	-	-	-	-

FDD and BAS maintenance

BAS maintenance, especially calibration of critical sensors, will make the FDD more reliable in its diagnostics. Note that some FDD will automatically detect sensor issues. Typical issues include:

- Poor sensor locations resulting in unreliable readings
- Failed sensors
- Communication issues
- Sensor drift
- Insufficient number of sensors

FDD typically requires proactive actions by the operating team.



Sensor maintenance – with or without an FDD

Sensor issue problems:

- Most control systems are not subject to regular calibration.
- Incorrect readings of control sensors often have a significant impact on energy consumption, comfort and possibly maintenance (e.g. heat pump cycling).
- Frequent practice: calibration by exception:
  - If three out of four sensors indicate similar values, programming of the fourth one is corrected to show a similar value.
- When a BAS is used for FDD or just for trend monitoring and tests, sensors should be reliable and calibrated.

How to identify problems:

- FDD that has this feature
- BAS analysis to identify impossible and implausible readings
- Point-by-point verification of selected BAS sensors

Calibration – critical sensors

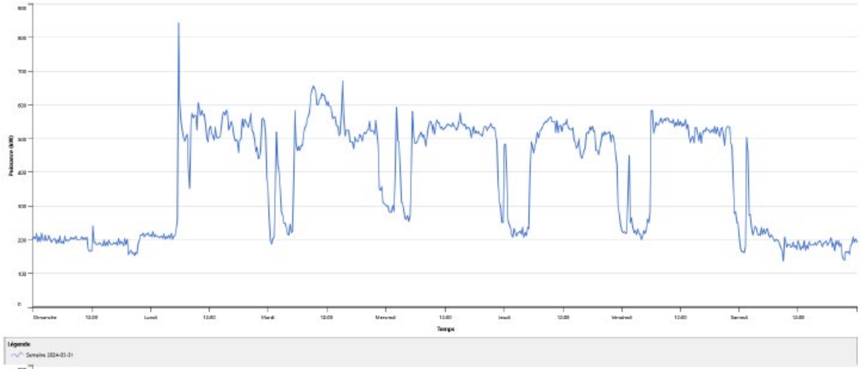
It is not necessary to calibrate all sensors such as room temperature sensors; their impact is limited and possible adjustments made by occupants can often cancel calibration benefits.

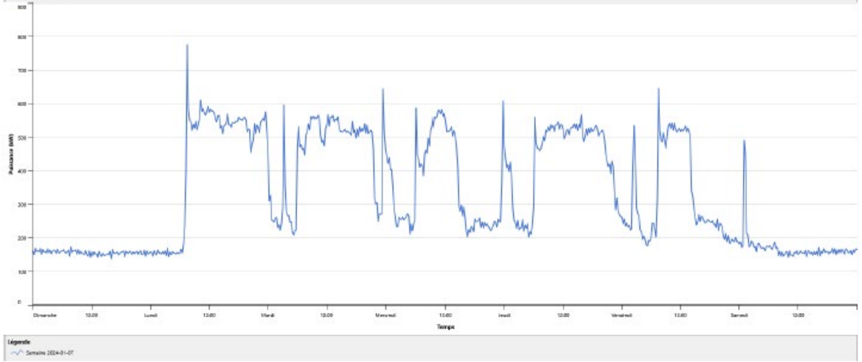
You must calibrate critical sensors – those for which the readings are key (in terms of energy consumption, stability, etc.) in the control sequences or for the FDD.

Sensors that are used for controling and diagnosing heat pumps are typically considered critical.

Improper set back recovery creating accidental peaks

- Heat pumps can result in morning recovery peaks.
- This issue can be detected by FDD as long as demand is part of the diagnostic rules.
- Good monitoring also provides the same diagnostic.





Conclusion and best practices

- Heat pumps are not just drop-in replacements for boilers and chillers.
- Adapt the control sequence to maximize the annual heat pump coefficient of performance/energy efficiency ratio.
- Know your heat pump system and building needs.
- FDD is an additional layer to ensure peak and sustained performance.

Questions and answers

- Any questions?
- Training and support webpage: visit this page to access all training and support materials

Save on Energy's Capability Building Program

- Save on Energy's Capability Building program helps increase awareness about energy-efficiency opportunities, enhance knowledge and develop skills in organizations and communities across Ontario so they can undertake energy-efficiency actions and participate in Save on Energy programs.
- The program includes tools such as workshops, webinars, training courses, coaching, peer learning and information resources, including guides and videos.

Learn more at https://saveonenergy.ca/Training-and-Support
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- Live training calendar: visit this page to easily register for upcoming events and workshops
- Training and support webpage: visit this page to access all training and support materials

Post-webinar support

One-on-one coaching: tailored support for managing energy resources effectively

Post-webinar support intake form

Coaching sessions conducted virtually: phone, video calls and email

Designed for organizations, new or old, seeking guidance

Thank you!

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