Energy Manager SWARM Technical Reference Guide

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What is SWARM?

SWARM is a program that deploys internet-enabled thermostats to small and isolated buildings that are not connected to the central Building Automation System (BAS). This leads to improved comfort with customized schedules that match occupant needs, improved HVAC maintenance with automatic alerts and phone-accessible equipment trend data, and energy savings from better scheduling and economizer control, if it is available.

Based on discussions with UC Davis IT and HVAC staff, the following technology requirements were developed to ensure the success of SWARM campus-wide.

SWARM Technology Requirements

- IT capabilities:
    - Ability to connect to a centralized web-based scheduling interface
    - Ability to assign building operators remote access to individual thermostat controls
    - Ability to assign permission levels to different user types (building occupant, operator, administrator)
    - Use web API capabilities to pull historical temperature and operating data into on-campus data systems
    - Ability to group thermostats by cluster/building
    - If thermostats use wireless communications, they should not rely on WiFi and should use a different frequency band than WiFi. Web-enabled thermostats cannot typically connect to the eduroam network, which requires a username & password.
- HVAC capabilities:
    - Allow view and control of HVAC equipment status (Cool/Heat/Fan, economizer position, etc.)
    - Control DX cooling, gas heating, heat pumps, up to 2 stages each
    - Run on-board fault detection and diagnostic (FDD) for economizer operation compliant with Title 24 Part 6 Section 120.2(i), and report faults remotely to the central interface
    - Ability to measure CO_2 and utilize demand control ventilation with economizer (when present in system)
    - Ability to use remote temperature sensors in lieu of thermostat on-board temperature sensor
    - Possibility of local thermostat override of pre-set schedule
    - Possibility of user-driven temperature setpoint adjustment, with centrally-controlled upper/lower bounds for adjustments
    - Utilize Optimum Start logic to ramp up building conditioning prior to occupancy

Technology Recommendations

The following technologies have been evaluated by the UC Davis SWARM team, but the Pelican and JCI technologies are the only ones that have been tested and installed on UC campuses.

Pelican T200/250

Features:

- Meets requirements

- Can control up to 2 stage heat/cool conventional AC or 3 stage heat + 2 stage cool heat pump
- Gateways can be hooked to ethernet port on campus network or connected via cellular network, depending on type
- Temperature and alarm sensors (TA1) provide external temperature monitoring and averaging
- PEARL Economizer Controllers provide fault detection, demand control ventilation, and VFD control
- Wireless Proximity Sensor (PRX1) detects when doors & windows are opened/closed
- Controlled via a web interface accessible on desktop and mobile
- No variable refrigerant flow control

JCI Tec-3000

Features:

- Meets requirements
- USB port decreases installation time
- In addition to AC and heat pump units, the technology works with VAV equipment, two and four pipe fan coils, and cabinet unit heaters
- ZFR Pro Router connects to campus network
- No variable refrigerant flow control

Honeywell T7350H

Features:

- Meets requirements
- Thermostat can control every unit in the system and works on up to 3H/2C or 2H/4C conventional AC systems of 3H/2C heat pumps
- Remote sensing capabilities for indoor/outside air temperature, occupancy, and discharge air available and allow lockout for extreme conditions
- Sharing of schedules and system parameters available with other devices on a LONWORKS network
- WebVision, a building manager, available for more comprehensive system management
- No variable refrigerant flow control

TCS Basys UbiquiSTAT

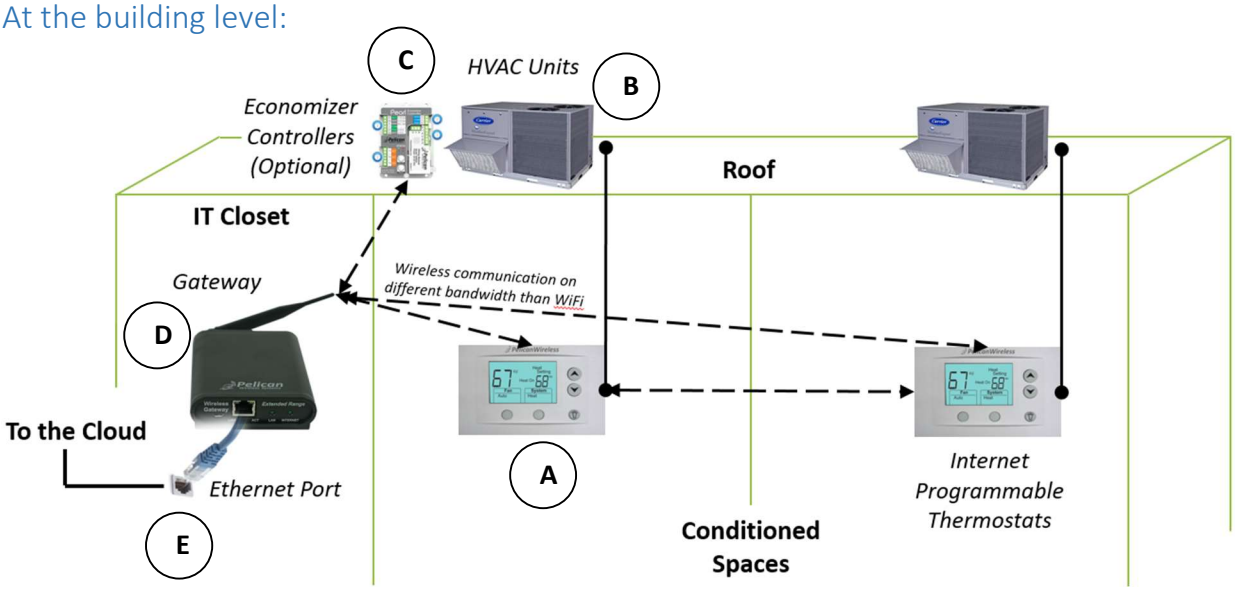
Features:

- Meets requirements
- Selectable BACnet or TCSbus communication
- Full-featured BACnet scheduling (SCHED-I-B)
- Models available with CO2, humidity, VAV, and economizer control
- 4 temperature inputs (1 built-in, 3 remote) for outdoor, discharge air, and remote room temperature with weighted averaging of remote room and built in
- No variable refrigerant flow control

How SWARM Works at UC Davis

At UC Davis, SWARM uses a Pelican Wireless cloud server to monitor and control HVAC systems through internet programmable thermostats. Different technologies may have slightly different set-up and connection details, but the concept should remain the same.

At the building level:



A. Internet Programmable Thermostats

Installed at UC Davis: Pelican TS200/250; other options include JCI TEC-3000, Honeywell T7350H, TCS Basys UbiquiSTAT, 75F SmartStat

- Installed in place of existing thermostats.
  - No new thermostats added or zones created.
  - Possible to add a remote thermostat to track temperature and balance conditioning within a zone for zones that are too big or improperly balanced.
- Schedule is determined by occupant and set by SWARM team.
  - Physical thermostat interface can be locked if in a more public space like lecture hall or unlocked if in a space like an office.
  - If unlocked, the schedule can be overridden by occupants for a few hours.
  - Building manager can create events to deviate from schedule.
- Thermostats can communicate with the gateway (D.) and other thermostats.
  - Gateway can reach thermostats up to 300 feet unblocked or 200 feet or less when factoring in walls and enclosures.
  - Thermostats can reach other thermostats from around 30 feet away.
  - Thermostats that are connected to the gateway can connect thermostats that are out of reach by acting as a waypoint.
  - If the thermostats are not quite close enough to each other to connect to the gateway, a signal repeater can be added to bridge the connection and avoid installing another gateway.

- If the AC unit connected to the thermostat has an economizer with a controller (C.), a CO_2-enabled thermostat can be added to receive a rebate from the utility.

B. HVAC Units

- The thermostats record data from the units and send it to the cloud.
    - This includes the fan, heat circuit, compressor, and economizer (if applicable).
- The units can be controlled remotely using the web interface.
    - Troubleshooting is easier for the HVAC techs.
- See Figure 1 for one example of how the thermostat is connected to the HVAC unit. Generally, the existing wiring can be re-used and technicians can simply swap the existing thermostat with the Pelican thermostat.

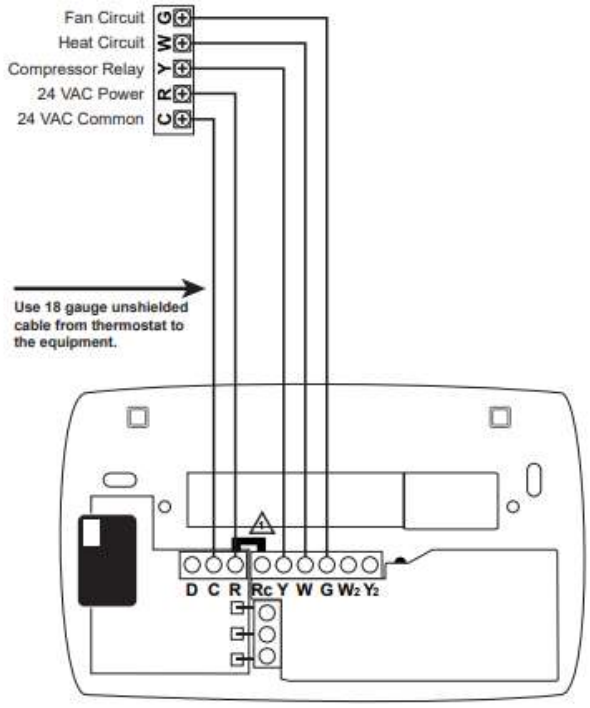


Figure 1: Sample Thermostat Wiring Diagram

C. Economizer Controller (Recommended if economizer is available)

Installed at UC Davis: Pelican PEARL Economizer and Demand Ventilation Controller

- If the HVAC unit has an economizer, control and monitor it with an economizer controller.
    - This ensures that the economizer is actually working and allows for more efficient HVAC use.
    - Make sure the unit is controlled by a CO_2 sensing thermostat to receive a utility rebate for demand ventilation control (applicable to PG&E and possibly other utilities).
- See Figure 2 for an example of how the economizer controller is hooked up to the HVAC system and the thermostat.

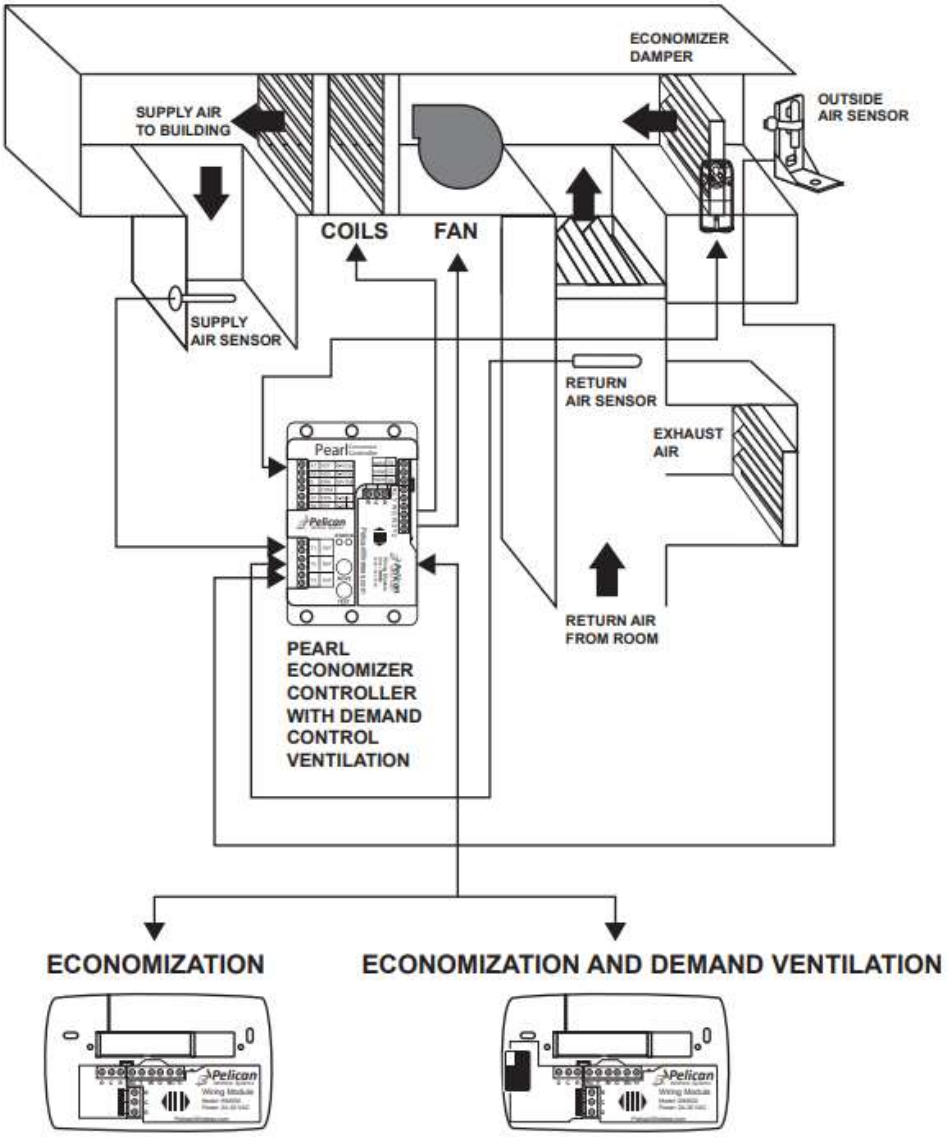


Figure 2: Sample Economizer Controller Diagram

D. Wireless Gateway

Installed at UC Davis: Pelican GW400 Ethernet Gateway, Pelican GW400-LTE Cellular Gateway

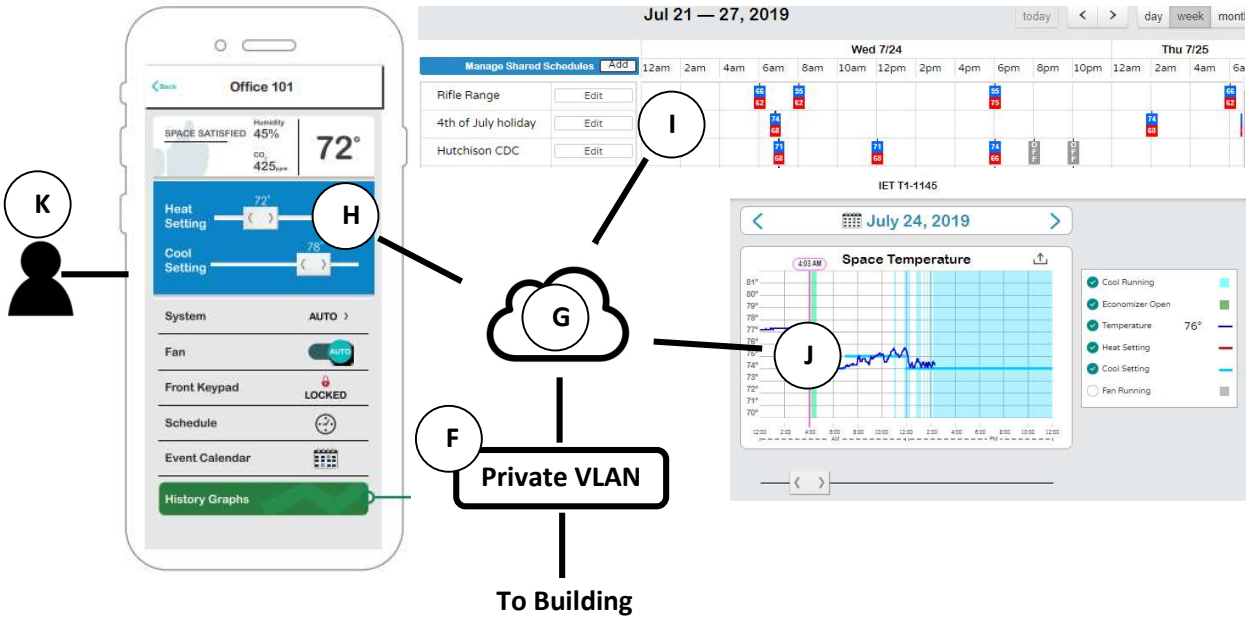
- Gateway acts as a bridge between the building and the cloud-based database and web interface.
    - No data is stored at this point, only transferred.
- The Pelican gateways do not use the same bandwidth as the WiFi network, meaning that they do not interfere with and cannot be interfered with by the WiFi network.
- There are different options for how the gateway connects to the cloud:
    - It can connect to an Ethernet port (E.) and from there either:
        - Through the general campus network to the cloud server
        - Through a private virtual LAN network (private VLAN) specifically set up with a private address for SWARM use

            - In this case, the gateway must be assigned a static IP address via Pelican that is used to connect with the cloud.
    - Alternatively, the gateway can communicate through a cellular network to the cloud server.
        - This is often more expensive, but it is a good option if there is no access to a wired Ethernet port or if your IT team does not want the thermostats connected to the campus network or a private VLAN. UC Davis's IT team has deemed Ethernet-connected gateways to be an adequate connection method.
- The gateway and the Ethernet port are housed in a place that requires a key to access
    - This can either be inside an IT or maintenance closet or, if the building is not equipped with one of those, inside of an enclosure specifically installed for the SWARM project.
    - Ideally, the location of the gateway will be close to any IT and telecom equipment in the building so that the Ethernet port is easy to install.
    - It should not be located near any large metal structures if possible; this will interfere with the wireless communication.

E. Ethernet Port (Recommended connection for gateway)

- If using an Ethernet-enabled wireless gateway, an Ethernet port will most likely have to be installed, especially if the gateway is connecting to the cloud server over a private VLAN
    - This will be done through the IT department, who will need to know the location of the desired port and the network you want to connect the gateway to.

In the cloud



F. Private VLAN (Recommended) / Campus Network / Cellular Network

- The most secure way to transfer information from the buildings to the cloud server is through a private virtual LAN (VLAN) that is specifically used for SWARM.

- If there was an electric meter installed for the SWARM project, it will be on a separate VLAN from the thermostats.
- The VLAN is created and operated by the campus IT team.
    - The client used for the cloud server and thermometers (Pelican for UC Davis) will be given access to the VLAN to connect to the cloud server. See the IT module in this toolkit for more details.

G. Cloud Server

Used at UC Davis: Pelican Wireless

- All readings from the thermostats are sent to a central database where they are compiled and stored so that they can be accessed at a later point.
- The VLAN or other network connection connects the cloud to the building data, and it is accessed via a unique website URL assigned by the cloud client (Pelican for UC Davis).

H. Thermostat Control

Used at UC Davis: Pelican Wireless

- To view the readings from the thermostat and status of the HVAC equipment:
    - Access the specific, secure URL provided by the cloud server client.
    - On the dashboard, you can view any building in the SWARM system that you have installed the thermostats in.
    - See Figure 3 for an example:

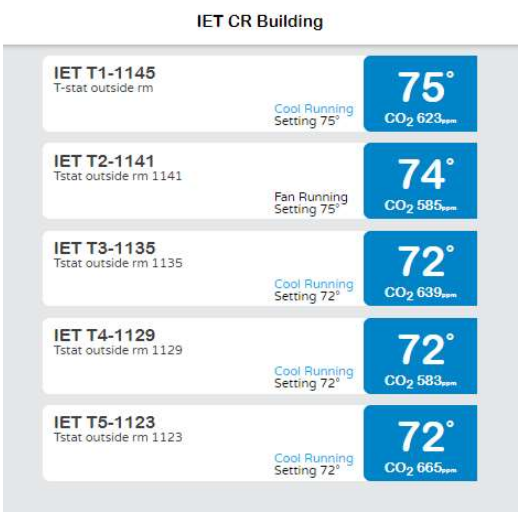


Figure 3: Sample Building Dashboard

- Within each individual thermostat, you can:
    - See the temperature in the space and, if the thermostat is CO_2 sensing, the CO_2 level.
    - Adjust the set points, fan settings, physical keypad access, which schedule to run, and economizer status, as shown in Figure 4 .
    - These views are useful for HVAC technicians trying to troubleshoot the system and a building manager interested in changing the set points.
    - From this view, it also possible to create a new event (J.)

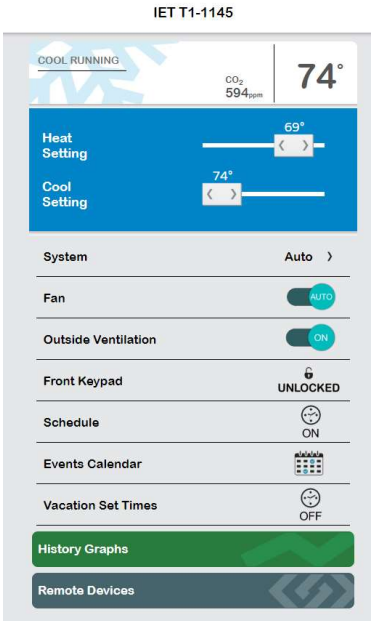


Figure 4: Sample Thermostat Dashboard

I. Thermostat Schedules

- A main feature of the SWARM program is programming building HVAC use around a set schedule.
    - Schedule is determined by the building manager.
    - SWARM can create a different schedule for the weekend than the week, as shown in Figure 5:

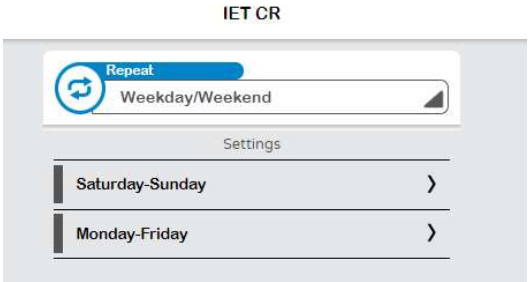


Figure 5: Sample Building Schedule Page – Week

- Within the day view of the schedule, the building can perform an “optimum start” which means that the building will ramp up prior to occupancy.
    - On this page, you can adjust the set points for different times of the day.

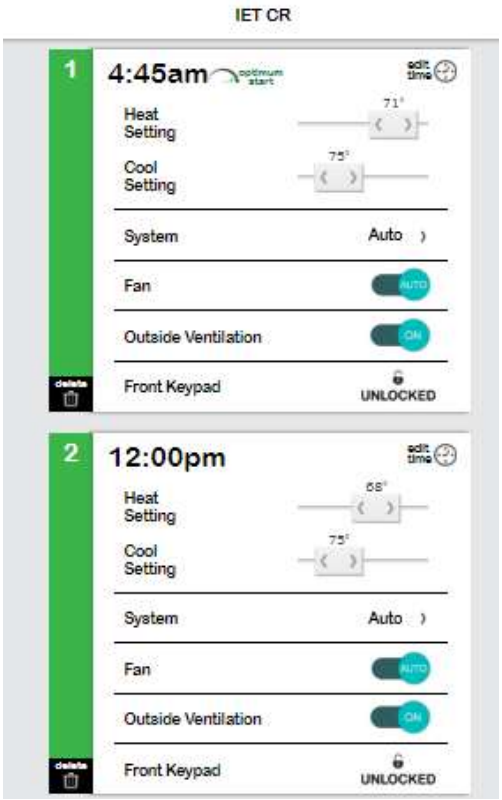


Figure 6: Sample Building Schedule Page – Day

- For special events that will require a deviation from the normal schedule:
  - Schedule an event by going to "Events Calendar" on the Thermostat Dashboard (see Figure 4).
  - Adjust any set points or equipment necessary for the event.
  - This is what building managers will use when adjusting the schedule for a specific time period.

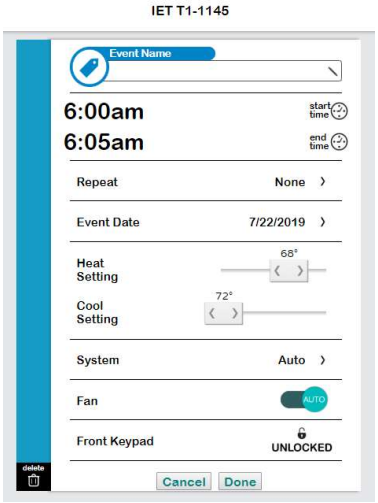


Figure 7: New Event Creation

- To view the set point schedule of all buildings and thermometers in the system, view the Schedule Dashboard.
    - Create events and edit any building or thermometer schedule.

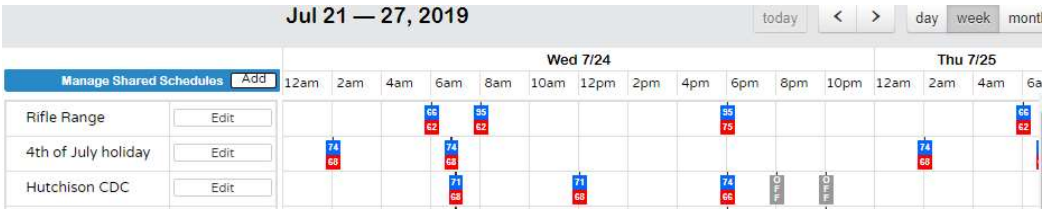


Figure 8: SWARM System Schedule Dashboard

J. Building History

Used at UC Davis: Pelican Wireless

- To troubleshoot the HVAC system, review cold and hot calls, and view equipment statuses in general:
    - View the "History Graphs" from the Thermostat Dashboard (see Figure 9).
    - By scrolling through the day, you can observe when the fans were running, when the cooling or heating unit was running, when and how much the economizer was open (if applicable), and compare outdoor, supply, and return temperatures.
    - This is the main page that the HVAC technicians will want to look at when troubleshooting a system.

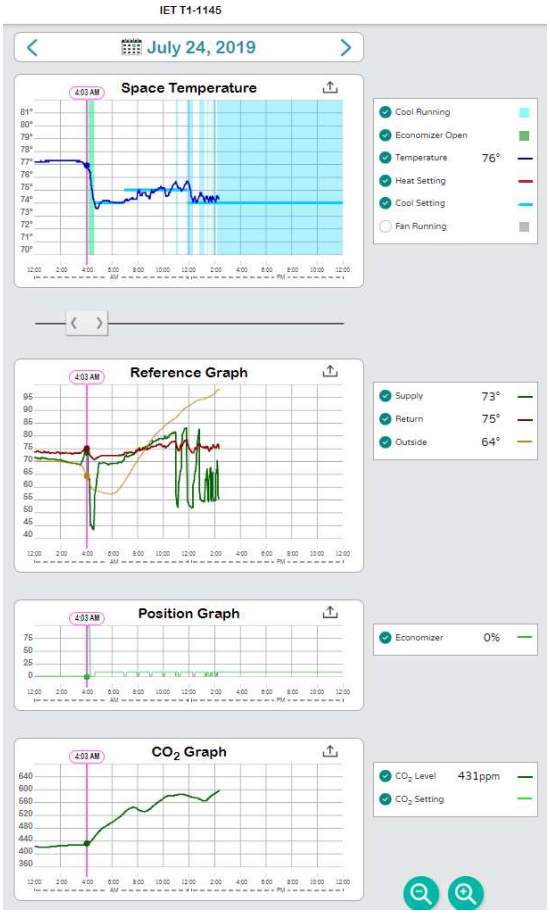


Figure 9: SWARM History Graphs

K. User Access

- Two types of access: User and Admin.
    - Admins are typically energy managers, anyone working on the SWARM program, and HVAC technicians.
    - Admins can see all history graphs, adjust any schedule or set point, and add buildings or thermostats.
    - Users are typically building managers who only need to access the thermostats of their building.
    - Users can only see the Thermostat Dashboard for their thermostats.
    - To add a new user, just assign them a username and give them access to specific thermostats (see Figure 10).

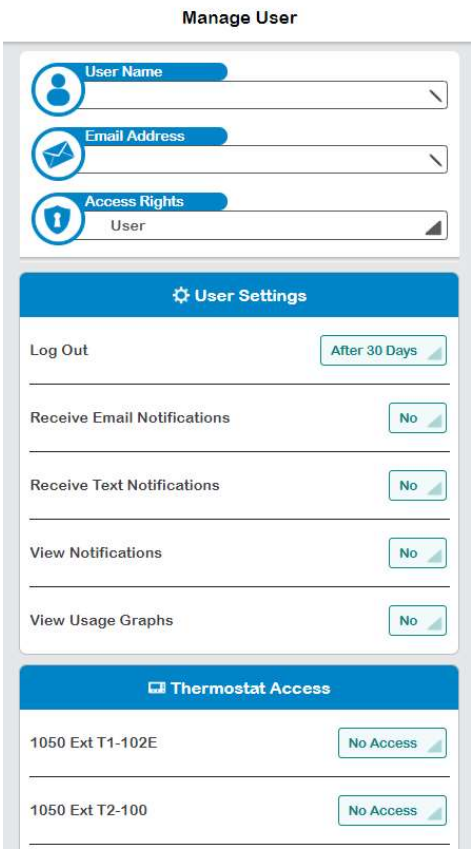


Figure 10: New User Page

Getting SWARM Started on Your Campus

Identifying SWARM Buildings

- Start to identify potential SWARM buildings on your campus
    - Begin by finding as many buildings as you can that are not connected to the central building automation system.
    - Small buildings, temporary classrooms or offices, or buildings somewhat isolated from the rest of campus are usually good candidates.
- Try to group any of these potential SWARM buildings by proximity
    - If there are a number of them clustered together, it is possible to use a single gateway for all of them which is more cost effective.
- Finally, identify just a few buildings from the list to use for a pilot program that fit most, if not all, of these criteria:
    - Metered, with access to utility data history spanning at least one year.
    - Has flexible HVAC requirements; offices & classrooms are better than labs because temperature does not need to be consistent 24/7.
    - HVAC units have economizers.
    - Does not use natural gas for heating.
    - Relatively large energy footprint compared to other identified buildings.

Budget

- Using the provided Excel spreadsheet, "SWARM Toolkit Budget Estimate", begin to estimate the cost of implementing the pilot program.
    - On the "Itemized Budget" sheet, add your first few buildings and answer the questions to guide the potential implementation costs of the building.

Table 1: Budget Information Input

	Pilot Building A	**Pilot Building B**	**Pilot Building C**
Building Name:	Building A	Building B	Building C
Does the building have a meter?	Yes	No	
How many HVAC units does the building have?	5	2	
Do the units have economizers?	Yes	No	
How many tons are the units?	8	5	
How many thermostats does the building have?	5	2	
Is this building/collection of buildings relatively spread out?	No	No	
Does the building have a maintenance/IT closet?	Yes	No	

- The estimated costs are based on the SWARM program at UC Davis.
    - If using the same equipment as UC Davis's SWARM program, these costs should be the same, but labor costs may vary and the necessary equipment will vary by building.

Table 2: Estimated Itemized Costs

Equipment	**Cost**	**Building A**	
Tstat	**$172.00**	0	$0.00
Tstat CO2	**$297.00**	5	$1,485.00
Z8 Zone Controller	**$799.00**	0	$0.00
Gateway	**$150.00**	1	$150.00
Repeater	**$100.00**	0	$0.00
Enclosure	**$185.00**	0	$0.00
eGuage	**$499.00**	0	$0.00
CT	**$ 46.00**	0	$0.00
TA1	**$ 16.00**	0	$0.00
RT1	**$105.00**	0	$0.00
Backplates	**$ 9.00**	5	$45.00
PEARL	**$165.00**	5	$825.00
Entercept	**$650.00**	0	$0.00
Bellimo Actuator (LF24-SR)	**$198.80**	0	$0.00
Mounting Kit (ECON-ZIP_LF1)	**$ 36.80**	0	$0.00
Beli Actuator (LMB24-3-T)	**$ 65.60**	0	$0.00
Beli Term Strip (LMB24-SR-T)	**$108.80**	0	$0.00
Software			
Pelican Subscription (per year)	**$ 2.99**	5	$14.95
Equipment Sub-Total		**$**	**2,519.95**
Labor			
Enclosure	**$250.00**	0	$0.00
Receptacle Install	**$500.00**	0	$0.00
eGauge	**$562.00**	0	$0.00
Entercept Install	**$850.00**	0	$0.00
NAM	**$600.00**	1	$600.00
T-stat	**$ 94.00**	5	$470.00
PEARL	**$188.00**	5	$940.00
Labor Sub-Total			**$2,010.00**
Rebates (per ton, max. $1500 per unit)	**$100.00**	40	**$ 4,000.00**
TOTAL		**$**	**529.95**

Equipment Cost Breakdown

- The new thermostats will be a 1:1 replacement of the existing thermostats.

    - If the HVAC units have economizers, we recommend getting CO_2 sensing thermostats, economizer controllers, and actuators for the economizers so that the building is eligible for larger rebates.
- Each building will need one gateway unless there is a cluster of buildings that has thermostats within ~25 feet of each other between buildings.
    - If the building is very spread out and thermostats cannot reach each other or the gateway, a repeater may be necessary.
- If there is no convenient, secure maintenance or IT closet for housing the gateway and Ethernet port, an enclosure will need to be installed. This enclosure cannot be metal.
- If there is not an electricity meter installed on the building, one may have to be purchased if utility metering is desired
    - It should be able to connect to a central database, similar to the thermostats
    - It will be sufficient to purchase a small meter (instead of PG&E installing one) and connect it to multiple CTs
        - Size these based on the size of the transmission line you intend to monitor
    - This is not necessary to do for every building. Once there are a few buildings with sufficient baselines, it can be assumed that the non-metered buildings have similarly shaped baselines unless they have significantly different occupation patterns.

Stakeholders

SWARM Team

- It helps to have a team of a few students or staff under the energy manager who spend most of their time on SWARM implementation.
    - We have found success with either a graduate student or full-time staff member running the day-to-day operation of SWARM while the energy manager or other energy and engineering team leader oversees the broader direction of SWARM.
    - Additionally, we have found it helpful to have part-time undergraduate interns to help out with the site visits, getting the equipment set up, and putting in work orders.
    - This team will hopefully grow with SWARM on your campus, but initially it is helpful to at least have one other staff member or student working on SWARM besides the energy manager.
    - If this is infeasible, the HVAC & Refrigeration team would be a good day-to-day overseers of the program.

Facilities Management

- The facilities team will be the group of stakeholders with the most day to day interaction with SWARM, especially the HVAC team.
    - First, the SWARM team will put in work orders to facilities management for the installation of the thermostats.
    - After everything is in place and set up, the HVAC team will monitor the remote equipment data for any potential issues such as a system running 24/7 or not at all.
    - Additionally, they will use data from SWARM when responding to cold or hot calls by building occupants.

- It is crucial for the facilities team to understand the benefits from SWARM relating to equipment maintenance and building temperature history.
    - We suggest presenting our Facilities Management Module to the facilities team as soon as possible and providing training on best practices and helpful tips for interacting with the web interface.
    - This will hopefully help increase their engagement with and enthusiasm for SWARM.
    - The UC Davis SWARM and Refrigeration team can be sources of training and information if need be.

IT Team

- The IT team may be the stakeholder with the most concerns around SWARM and the most potential to slow the SWARM process down.
    - The most effective way for SWARM to connect building thermostats to the web database is through a VLAN that must be set up by the campus IT admin.
    - The Communication Resources team will be the ones installing the Ethernet ports in the building to allow the gateways to connect to the VLAN.
- The campus IT admin will most likely have security concerns about the SWARM program and the way the technology interacts with each other, the campus network, and the external cloud client.
    - We suggest presenting our IT Administrators Module to the IT team to help address concerns.
    - If you choose to opt for technology other than the Pelican equipment and web client that we use in the UC Davis SWARM program, it is important to address the same concerns noted in the module.

Campus Administration

- After developing your budget, create a timeline for implementing the pilot SWARM program and a presentation of the broad overview of SWARM.
    - This can be very similar to the Campus Energy Module slide deck, with minor editing to the Next Steps section.
    - The key points to focus on are that the program can have a reasonable payback period, it can make life easier and safer for the HVAC team, and can reveal temperature history in isolated buildings around campus.

Building Management & Occupants

- The building manager will be the main point of contact for the building when the SWARM team is coming on site or determining the schedule for the building.
    - They will have access to the remote thermostat controls for the building.
    - They will also have the ability to create special events to deviate from the scheduled set points in the space.
- When developing the SWARM program, it will be important to identify the appropriate building manager for each of the buildings being considered for the pilot program and contact them with information on SWARM and how it will affect their building.
    - We will provide communication templates in our Building Manager Module.

    - The most important talking point is that one of the program's main goals is to increase comfort in the space and make sure that the building is meeting the air conditioning needs of the space.
- The building occupants will most likely being the ones making cold and hot calls to the maintenance team.
    - They will be more convinced of the efficacy of the HVAC system if the HVAC team can show them temperature history and equipment status data as proof of either responses to the cold and hot calls or the lack of need for a response.

Setting Up a SWARM Building

Determine SWARM Eligibility

- After creating a list of potential SWARM buildings for your pilot program in your initial audit (see Identifying SWARM Buildings), the next step will be determining and contacting the building managers.
    - You will want to set up a site visit, ideally with the building manager present to show you around.
    - It will be helpful to bring a floorplan, mechanical drawings if you can acquire them, and perhaps a list of standard questions for the building manager about the current conditions of the heating and cooling of the space.
    - The HVAC or Refrigeration team may also have a better understanding of the HVAC systems in the building.
- There is no set criteria for what makes a building eligible for SWARM, but ideally the building will have a good amount of energy savings opportunities
    - This might mean that the HVAC system is running 24/7 or that the thermostats do not have any set schedule
    - For the first few buildings in the pilot program, it will be helpful if the building has a locked electrical or IT closet that the gateway and Ethernet port can be installed in so that you do not have to spend money on an enclosure and so that the Ethernet port is close to the rest of the IT equipment in the building, making it easier and cheaper for the communication resources team to install the Ethernet port.
    - Finally, the HVAC team should be included in the decision about SWARM eligibility.
        - There may be units or economizers on the building that the HVAC team sees as areas of potential savings, either for energy or maintenance time, that the SWARM team was not able to identify on their initial visit.

Collect Information on Site

- Ideally, the buildings you've chosen for the SWARM pilot program have meters for interval data
    - This will provide you with the baseline data necessary for measuring the savings of the SWARM program, which will be crucial for showing the value of the program.
    - If this is not the case or you do not have access to this data for some reason, there are a few alternative options for collecting baseline energy data:
        - One is to install an energy meter at the site (this can simply consist of an energy logger and a few current transformers) and log HVAC runtime data prior to SWARM installation for at least a month to understand use.

        - Another option is to make an estimate about the previous schedule of the building using either observations from your site visit or perhaps occupancy loggers, if available.
    - With this data, combined with the tonnage of heating and cooling controlled by the thermostats, you can estimate the energy use for the HVAC system in the building
- Note the number and location of thermostats in the building so that you can replace them with the new wireless enabled thermostats.
- Locate the intended location of the gateway and Ethernet port.
    - IT closet is ideal.
    - If the building is spread out or you are working on implementing a cluster of buildings into SWARM, you will want to measure the distance between the gateway and the thermostats.
        - Pelican gateways can usually connect to thermostats 250-300 feet away unobstructed, but this is more like 150-200 with a wall or two in the way.
        - The thermostats can connect to each other from a range of about 30 feet.
        - If there is a thermostat farther than connecting-distance of either the gateway or a connected thermostat, you will need to install a repeater.

Order and Connect Equipment

- After the VLAN is set up by IT, request that the communication resources team install an Ethernet port that connects to the VLAN.
    - Provide them with a floor map and photo indicating the exact location on the wall to install the port, along with the VLAN network.
- Order the equipment necessary for the building, including:
    - Enough thermostats to replace all the existing thermostats in the building
    - One gateway
    - Any repeaters necessary
    - If the building has economizers on the HVAC units, purchase economizer controllers for each unit and make sure that the thermostats connected to these units have CO_2 sensors so that you can apply for the full rebate from your utility.
- Set it up and test it before installing it in the field.
    - Plug the gateway in and connect it to the SWARM network by creating a new gateway on the web interface using the serial number on the gateway.
    - Contact Pelican to assign the gateway a unique static IP address.
    - Turn on the thermostats and connect them to the gateway.
        - Assign them the desired name, set points, and schedule on the SWARM website.

Install Equipment and Assign Access

- Take the gateway out to the building and connect it to the port.
    - Make sure that the building shows up on the SWARM website before leaving.
    - Put in a work order to the facilities team to install the thermostats and the economizer controllers if applicable.
    - Finally, make sure that the thermostats are live and visible on the SWARM website..
- Give access to the remote thermostat control to the building manager(s).

    - At this point, run them through the part of the Building Manager Module that describes how to use SWARM in their building and make sure they are comfortable with the controls and event scheduling.
- At this point, the building should be ready for monitoring and tracking.

Holiday Shutdowns

- Shutting down buildings on holidays can be an easy way to save energy using SWARM.
    - Send out emails to each building manager in SWARM prior to a holiday asking if the building will be occupied.
    - Create a holiday event (see Thermostat Schedules) on the schedule dashboard that shuts off the HVAC system for each unoccupied building.
    - If the building user indicates that the building will be occupied, do not adjust the schedule in that space.