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Building Automation System Architecture and Design for

the ***ICE-9*** *Building Automation & Control System*

ICE-9 Building Automation

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Preface:

This document is a rambling collection of information chunks which are not written to address a singular audience. This should not be taken as a complete work but rather as a collection of pieces which may form the basis of a complete work after a whole lot of work.

Much of this document was written using voice recognition which is amazing but far from perfect. This document has not been proofread completely yet and there may be egregious grammatical errors contained within.

ICE-9 is only used as a working title for this system and will be replaced once a more suitable name is suggested.

Background:

It's 2017 and the Internet of Things (or IoT) paradigm is now the driving force in the automation industry. Historically, there have been dozens of proprietary approaches taken to automation, all looking to achieve more or less the same goals. The Internet of Things has enabled the industry to standardize on ubiquitous interconnection technologies and protocols, and to eschew proprietary solutions, driving down cost and greatly enhancing flexibility. We cannot predict the future but we can say with great certainty the future will be networked via TCP/IP, Ethernet, and CAN-bus.

ICE-9 is an next-generation distributed` building automation system built upon the IoT standards which have been universally adopted by industry players such as IBM, AT&T, Intel, Google, and Amazon just to name a few. ICE-9 combines highly successful hardware platforms for advancing quick development with the most successful software framework for interconnecting resources on any scale to create a system which has unsurpassed flexibility, adaptability, openness, and customizability.

The ICE-9 system is not tied to singular vendors, is exceptionally efficient, exceptionally flexible, and is as future proof as possible. If the customer wants it, we'll connect it.

ICE-9 Design Philosophy, Objectives, & Notes:

This system design meets several objectives:

- Minimize design time
- Minimize cable requirements in terms of both total length and varieties
- Minimize installation requirements
- Minimize system cost
- Minimize support cost
- Minimize operational cost / energy consumption
- Minimize prerequisite knowledge for programming & reconfiguration

- Maximize reliability
- Maximize serviceability
- Maximize flexibility & reconfigurability
- Maximize information security
- Maximize hacker resistance
- Maximize efficiency of resource usage once installed
- Maximize interoperability with ecosystems & devices from other vendors
- Maximize use of open standards and open source tools
- Maximize manufacturability
- Maximize design lifespan
- Maximize the number of people who can design future components for the system

Design time is minimized through the use of standardized system core modules which are based on ARM processors and programmed through widely adopted development environments with ubiquitous support in the STEM world. The bulk of the sensing and control resource nodes are based on the Teensy 3.2 platform which makes use of efficient ARM Cortex M4 micro controllers with integrated CAN-bus controllers. This platform allows the Arduino Integrated Development Environment to be utilized to customize behavior of individual modules. More computation intensive modules with video output are based on the Raspberry Pi 3 single board Linux computer with additional IMS circuitry and open source tools from vendors such as IBM.

All modules are joined via RJ-45 cabling which provides both data and power, resulting in a scenario where modules are simply plugged into each other to create a finished system. As the needs for a building change, its functionality can be changed on a module by module basis without having to enlist a contractor to reengineer the system. Standard Cat5 Ethernet cable is used for module interconnection. This allows all cables to be pre-tested, color coded, and available from stock at almost any cable vendor. The rest of the cables in the system are all standard HDMI, Ethernet, USB, DMX, or TOSlink. No proprietary connectors are used.

The use of an in-house designed system allows IMS to deliver exactly what is required for the application. The granularity provided by ICE-9 allows any subsystem to be addressed individually and to be configured to exactly what is required by the application. If that application is redefined or the needs change, the system may be easily reconfigured to fit the new needs without re-engineering.

Each module uses a standardized design, most requiring zero configuration. Software configuration is not required by any building resource module and for modules such as lighting controllers where are you could conceivably have more than one zone of operation, a small rotary switch allows the zone to be selected with a small screwdriver. Individual modules maybe replaced by service personnel in minutes from a standard parts stock or even cannibalized from another location in an emergency. No system reconfiguration is necessary. All modules contain self diagnostics and functionality that allows a system hub to monitor their healthy operation.

By providing centralized monitoring and control of energy consumption, energy expenditures can be reduced or eliminated.

All system components are designed for robust, high reliability operation and long life. A system monitor constantly scans all devices in use and will summons maintenance at the first indication of trouble, proactively eliminating downtime or occupant discomfort.

Because all system components are joined with modular wire connections, the resources in any given building may be redefined at moments notice and almost without restriction. At the top level all system switches and sensors become inputs and all devices which perform work become outputs. The building engineer has complete flexibility to draw any association between any input and any output as well as the ability to add timers, counters, and other logic. These configurations may range from a simple system like a switch controlling a lighting fixture all the way to a complex scenario where that light is also controlled by a schedule on a timer and affected by occupancy sensors with the additional capacity to be remotely controlled and monitored.

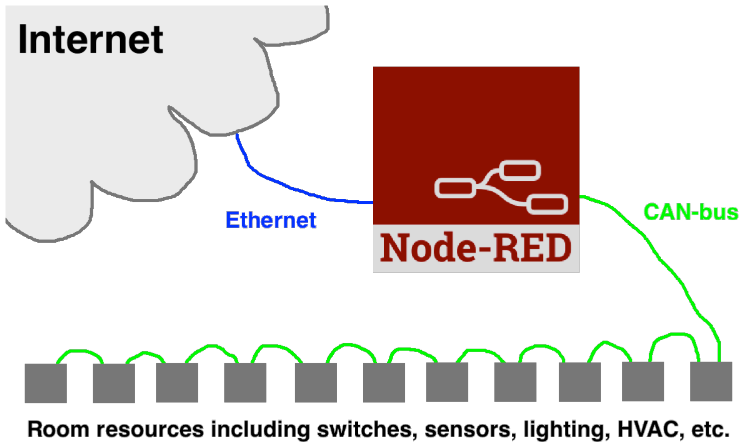
Data is kept secure by making it physically inaccessible. All CAN-bus connections remain inside the locked structure, inaccessible from the outside. Ethernet is delivered to the structure through hard conduit, making unauthorized access exceptionally difficult. No secure data is transmitted over insecure RF links and no RF links are used in most system configurations.

With programming, ICE-9 will integrate with Apple's Home Kit. This provides access to a great number of third-party solutions including door locking systems which have already been vetted by Apple.

ICE-9 integrates with the system hubs from a number of other vendors including the Amazon echo, the Google whatever you call it, and IKEA's Tradfri hub for home automation components. This provides access to a great number of third-party solutions such as voice control, *(insert Tradfri components here)*.

ICE-9 Architectural Overview:

ICE-9 leverages the power of three principle technologies; the Internet, Node Red, and CAN-bus.



At its most basic level, you can think of ICE-9 as a collection of building resources connected to a CAN-bus network in each room, monitored and controlled via Node Red software. Node Red is then connected to the Internet for remote monitoring and control.

While most people are familiar with the Internet, Node Red and CAN-bus may be new.

Node Red is a graphical drag-and-drop software environment for interconnecting resources on any scale which is powered by Javascript, the language that literally runs the web. Written by IBM's emerging technologies division, Node Red was placed into open source and now enjoys adoption across the industry by players as large as AT&T where it forms the basis of their IoT offerings. Node Red allows a building engineer to construct control programs in minutes using a graphical interface which used to take weeks of work from an expensive and specialized programmer.

CAN-bus is a worldwide standard for industrial automation networks which controls cars, refineries, operating room diagnostic devices, elevators, industrial robots, Boeing and AirBus airplanes, and new NASA spacecraft among other uses. Thanks to its high reliability, CAN-bus has become the dominant local control network in industrial automation, replacing countless proprietary approaches. CAN-bus adds a level of the invisible fault tolerance, ensuring that all communications reach their destinations.

CAN-bus uses a daisy chained topology where each device is plugged into the next device in-line. In a typical installation this network would encircle the perimeter of the room, interconnecting all of the resources. In the ICE-9 implementation of CAN-bus, up to approximately 50 devices may be connected together on a single segment of cable which may be up to 200 m long. If more than 50 devices are required, CAN-bus hubs may be used to interconnect multiple segments of cable to accommodate those additional devices. IMS presently has designs for both two and four port hub devices which should accommodate all foreseeable installations, providing support for 200 devices and several hundred meters of cable in a single net. Multiple hubs may be used to expand capabilities even further.

One of the devices in each CAN-bus network is a more powerful computer based on the Raspberry Pi 3, a quad core 1.2GHz ARM based system running Linux. This computer runs the Node Red software as well as providing a number of other higher-level services. Typically for a classroom or other media rich configuration there will be one Pi-based node controlling every room. For economy or to accommodate unforeseen needs it is possible to connect up to 16 rooms per Pi using hubs. Architecturally, each Pi can support up to 16 lighting zones or 16 HVAC zones maximum.

Many vendors utilize RF communication for interconnecting their sensing and control networks. RF communications bring with them a great number of downsides. RF is susceptible to interference so proper operation cannot always be assured and all data is available for public reception necessitating extreme care and complexity when it comes to data security in the design. RF Systems are always more open to hacking and disruption and as time goes on the RF spectrum will only become more and more congested. When utilizing a radio connection power must still be supplied via wires so cable savings between wired and RF systems may be trivial while the potential reliability of an RF system is considerably less.

For these reasons ICE-9 is principally a wired system although it supports a wide array of wired and wireless technologies transparently. ICE-9 is interoperable with Ethernet, Bluetooth, Wi-Fi, and 315/488 MHz RF which is utilized by a number of systems from Philips' HUE lighting to Samsung's StartThings line to home automation devices from a number of vendors.

ICE-9 includes architectural compatibility with future ZigBee 802.15.4, Z wave, or other RF interfaces if these ecosystems are desired.

Under the hood an array of additional technologies including ARM, Javascript, Node.js, JSON, MQTT, and many others do the heavy lifting to enable a uniquely powerful system.

Internally, this system makes use of IBM's MQTT protocol for message transport and IBM's open source Node Red product to provide complex high-level control. MQTT and Node Red have been adopted as standards by IBM, AT&T, and many other organizations as the core of their Internet of Things technologies. Most large vendors are adding subscription database cloud services to their IoT offerings, however IMS provides this database functionality as an inherent part of the system; built-in. This database functionality allows for logging of all environmental parameters and energy monitors. Bridges to both BACnet IP and WWW are provided for remote monitoring and control.

At a speed of 1 Mbit/s, a maximum cable length of about 40 meters (130 ft.) can be used. This is because the arbitration scheme requires that the wave front of the signal can propagate to the most remote node and back again before the bit is sampled. In other words, the cable length is restricted by the speed of light. A proposal to increase the speed of light has been considered but was rejected because of its inter-galactic consequences.

Other maximum cable lengths are (these values are approximate) –

100 meters (330 ft) at 500 kbit/s
200 meters (650 ft) at 250 kbit/s
500 meters (1600 ft) at 125 kbit/s
6 kilometers (20000 ft) at 10 kbit/s

ICE-9 Core Module, Raspberry Pi, & Customization:

Designing an automation system for use in buildings with a 100 year service life requires careful consideration of all of the technologies involved. Most electronic components have a lifespan which is defined by their use, however some components have a lifespan defined by their age. IMS avoids the use of as many of these age-defined technologies as possible however the use of one of these technologies is simply unavoidable, that being Flash memory. In Flash memory, the device itself has a lifespan which is defined by use however the data contained within it has a lifespan defined by the elapsed time since the data was written. Almost all embedded processors today utilize Flash memory for firmware storage and while Flash is a mature technology that we rely on everywhere, it should be realistically categorized as long term temporary storage which in time will forget its contents unless they are refreshed.

Flash memory utilizes microscopic pieces of electrically insulated silicon to store data as electrical charges. Depending on the technology used to fabricate the Flash memory cell, these charges may last anywhere from 15 to 100 years under ideal circumstances. Elevated heat or atomic scale defects in the chip reduce that data retention time. In general, electronics today will have a service life which is shorter than the retention time of the Flash memory used within them so this lifespan issue isn't considered in most designs. Because our products are built to last a century, we have no choice but to treat Flash data integrity like no other builder and to solve the Flash data lifespan conundrum in our automation components.

Sensor and actuator automation nodes are built from a common core electronics module based on the ARM Cortex M4 processor, a relative the processor that powers iPhones and countless other electronic devices. This core module actually contains a pair of ARM processors, each with the ability to load data into the operating firmware memory of the other one. One of the two processors connects to the IMS CAN-bus, sensors, and other external hardware and is in charge of the operation of the node. A second, much smaller processor is charged with the task of insuring the primary processor's operating firmware is in tact, and reprogramming it if necessary. The primary processor is able to check and reprogram the second processor if necessary as well.

Flash is difficult to optimize for data retention when it is fabricated on the same silicon die as a high-performance, low-power CPU. In typical consumer applications this doesn't pose any sort of issue as 15 to 20 years of retention is typical however Flash may retain data for 100 years or more in chips which are optimized for storage. To address this retention issue we add a separate Flash memory device to the design which is optimized for data retention and characterized with a 100 year retention time while also being large enough to contain quadruple redundant copies of all operating firmware to allow for fault tolerance.

Once per decade, all nodes in the system undergo a flash memory refresh procedure to ensure that they will be reliable for the next decade and beyond. This feature differentiates IMS automation components from all other known automation systems.

To enable fast prototyping, the core module may optionally be built using a pre-programmed version of the second ARM which contains the PJRC Teensy Bootloader. This renders the core module compatible with the Teensy single board computer product line and programmable via the Arduino IDE. Once a prototype is completed.

This approach also leverages the scale of economy used to build these two computing platforms and reduces manufacturing requirements for IMS modules. The bulk of the IMS modules' circuitry consists of I/O components to connect these computing cores with the outside world.

Both of these core modules use ARM processors. One is better suited to provide the intelligence of individual building functions while the other is better suited to providing higher-level services.

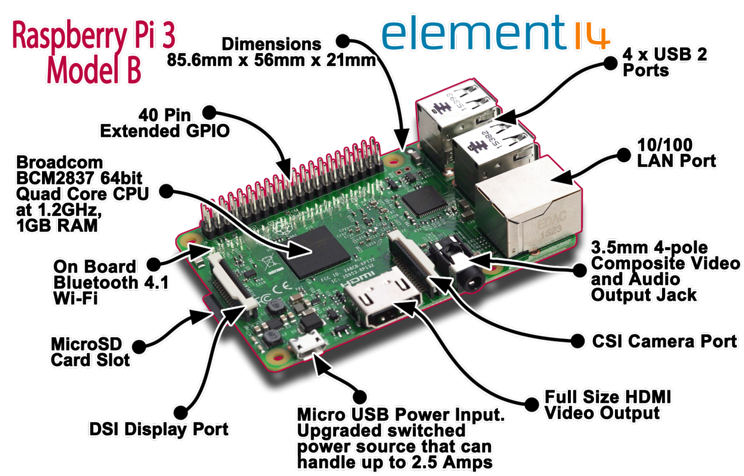
Ice core circuit description:
The Ice-9 embedded automation core module includes a large number of features in a very small package. The following bill of materials table lists all of the components used in the core module, their function, and criteria for choosing the specific devices used.

The major challenges include creating a design which can be built as (1) just to the application ARM processor, (2) the application ARM plus an integrity and reprogramming ARM, or (3) the application ARM processor with a Teensy boot loader. Option (1) covers typical building automation system deployments. Option (2) covers long life, high integrity installations. Option (3) allows for firmware development using the Arduino integrated development environment.

Part	MFG #	Description:	Notes:
U1	MK20DX256VHL7	K20 ARM	NXP ARM M4, 72MHz, CAN controller, ADC, Teensy 3.2 OBJ compatible
U2		KL04 ARM	NXP ARM M0+, 48 MHz, low power modes, Teensy MKL04 loader compatible
U3		16Mbit FLASH	100 year retention, sized for multiple redundant data images
U4		dual AND	Glue logic, low quiescent current
U5		CAN transceiver	3V3 operation, robust, high impedance, no load when unpowered
U6	MAX15062	3V3 Buck reg.	Power Supply, 5-60V input, 300mA out, made for harsh industrial environments, provides /RESET
Z1		CAN TVS	Adequate static protection for CAN bus
J1		Dual RJ45	Amphenol name brand, 50µ Au plating, 1.5A, 125V, shallow depth, rotation compatible footprint, inexpensive
J2, J3		20 Pos., 1.27mm	Compact header for board-to-board

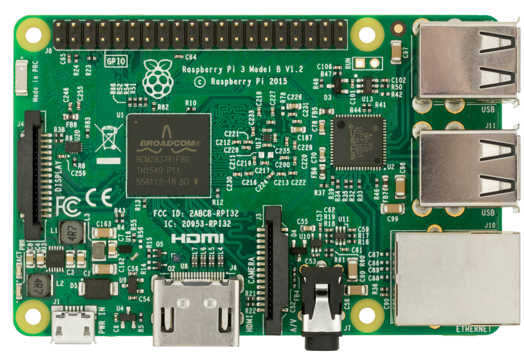
Embedding the Raspberry Pi for IMS

All the higher level functions of this automation system such as running Node Red, CAN routing, serving web pages, or providing video output are handled by nodes based on a single board computer running Linux; the Raspberry Pi 3 Model B. While initially intended as a computer for the educational market, the Pi has now been adopted by major manufacturers as an embedded Linux computer module for production use in high end consumer and professional grade electronics. Companies as large as NEC are now using the Pi core for intelligence in new products.



The Pi 3 Model B (shown to the right) comes as a bare motherboard which requires a couple additional resources to become a full fledged computer and a couple more to be an effective embedded core controller for an automation system. The cost of these additional components is trivial when compared to the savings provided by taking advantage of the Pi's scale of economy in manufacture and enormous development community.

The Pi is presently the number one computer in education and it enjoys worldwide support on grand scale throughout the STEM community. The I/O capabilities of the Pi and it's open source operating system provide an ideal foundation for a powerful embedded controller.

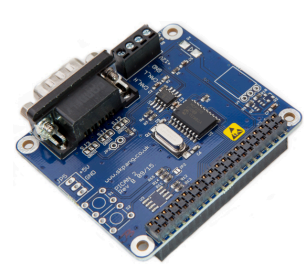


Code for the Pi can be written in JavaScript, C, Python, PHP, or a plethora of other languages.

Adding IMS Peripherals

Using the Pi as a building block allows an exceptional amount of intelligence and capability to be built into the system at a cost which is comparatively trivial but it does require some adaptation to meet IMS' needs. To utilize the pie as a building controller, a small selection of additional peripherals is necessary.

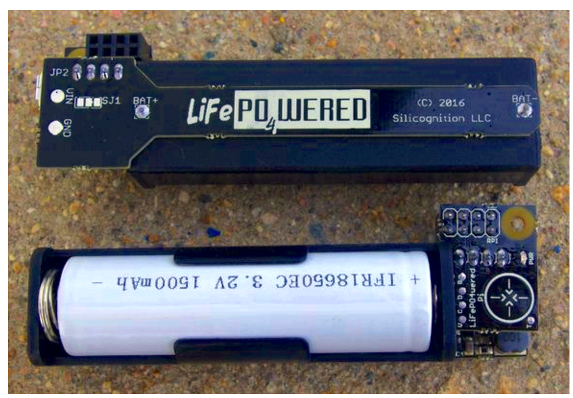
The first of these peripherals is a CAN-bus interface for communication with ICE-9 modules throughout the structure. A typical example of a CAN-bus peripheral expansion "hat" for the Raspberry Pi is shown to the right. This example uses different connectors for the bus than the IMS solution and is situated such that only a tiny heatsink may be used on the CPU or Ethernet/USB controller. Therefore, off-the-shelf products with this physical configuration are not suitable for production use by IMS



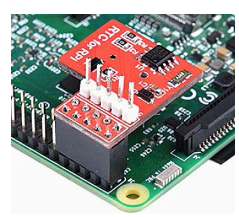
however the circuitry required to implement this function is fairly trivial.

The second additional peripheral required is in an uninterruptible power supply system with a long standby lifespan and zero danger of the ignition. This is necessary in order to ensure that the Pi, which is a Linux computer, is able to perform a clean shutdown in the event of power loss. There are multiple technologies available to use in a UPS design however most of them have serious downsides. Nickel metal hydride batteries have short lifespans with only moderate energy density and they are prone to leakage. They're not an option. Lithium polymer batteries have wonderful energy density however they experience substantially shorter lifespans when maintained at full charge and their lifespan can be measured in the low hundreds of charge/discharge cycles even when used as intended. Lithium polymer batteries also have serious issues with fire. These issues banned their use on the space shuttle and they require today's flight attendants to undergo additional training to deal with lithium metal fires. This technology would be a poor choice in a classroom setting. Another potential is the use of large super capacitors. Super capacitors offer several benefits including unlimited charge/discharge cycles, almost immediate charging, and long life. Unfortunately they are also quite expensive and limited in energy density. A super capacitor based solution is feasible but only to the extent of providing clean system shutdown immediately upon power loss. Even in this capacity, their use This could be problematic in the case of multiple short duration outages where are the power fluctuates wildly so a more stable supply with a longer run time is necessary.

One of the newest options is the lithium iron phosphate or "LiFe" battery. These cells combine the very high energy density of lithium chemistry with faster charging rates than typical lithiums and charge/discharge cycle counts in the low thousands, and without the fire and ignition issues of other lithium chemistries. The LiFe battery is the best solution available presently to provide not only clean system shutdown but to also maintain Data logging and operation during brief power outages, eliminating the need to reboot when power is reapplied unless the outage is prolonged.



A low volume commercial offering for such a LiFePO4 battery based micro-UPS has been identified from LiFePO4wered/Pi™. While the functionality of this design may be duplicated in volume fairly easily, it does utilize parts which are difficult to source in small quantities outside of China. For this reason in the near term it will be desirable to integrate this pre-existing solution with the other additional peripherals by providing a connector where it can simply plug in. The UPS subsystem must be capable of monitoring battery conditions and acting accordingly through software. This subsystem should also provide the facility to toggle power to the pie via a button. The identified solution provides these capabilities. The battery used is a standard 18650 form factor cell which snaps into a standard cell holder for easy replacement in 15 years. Chemical systems like batteries don't last forever.



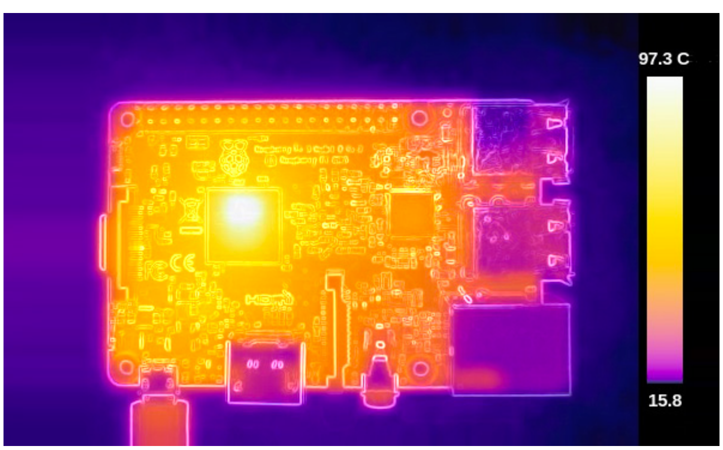
The third peripheral required is a battery backed real-time clock to ensure consistency of timestamps in file access and data logging. This is accomplished with a single-chip solution using a Dallas DS1307 or DS1232 real-time clock chip which is powered directly from the battery supply. An example of such a clock board is shown to the right in red. Again, the commercial offering in the example shown prevents the use of effective passive cooling.

Off-the-shelf Pi expansion boards providing all of these functions individually are available however there is no single offering which contains all of these peripherals and the offerings which are available all compete for use of the same I/O pins on the Pi. Additionally these peripherals must be provided while not compromising the space available for a high-efficiency passive heatsink for the CPU.

In the typical Pi configuration, only a single add-on peripherals may be used and that board sits directly above the CPU which needs additional cooling to operate at full speed. While that's not an issue when the Pi is used for educational purposes or for tinkering, it becomes a very serious consideration for embedded systems. To address this issue and turn the Pi into a workhorse embedded computer, the Raspberry Pi Foundation has re-issued the core of the Pi as a "compute module" in the form factor of a standard memory module which can plug into a board containing additional peripherals customized to needs.

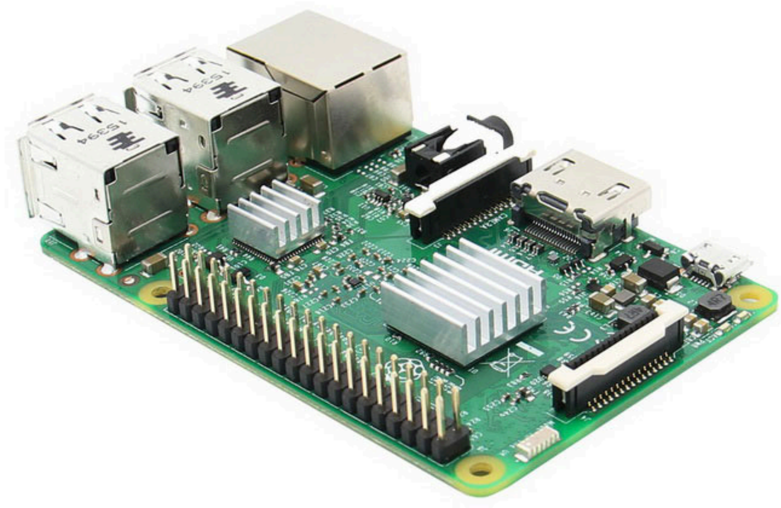
Using this compute module for IMS' needs would require re-implementation of both the ethernet/USB controllers and ports as well as the HDMI connector. These connections involve signals as fast as 5 GHz so this task would require professional electrical CAD software such as Altium Designer to be done properly. Designer is a $10,095 dollar package for the 1st year's license and $1850 for year 2 and on. Because of the quantities used by IMS, implementation of a complete new controller using the Pi compute module will not be cost-effective in comparison to use of the Pi 3 Model B unless a multiple thousand unit order is being filled. Even then there is probably little savings to realize in a compute module based design because of the additional requirements for manufacturing. There is no apparent downside I can see to use of the standard Pi 3 Model B along with a peripheral expansion board in a custom case. Removing the extremely high-speed signals from the IMS PCBs to be produced allows the CAD work to be accomplished using CERN's KiCAD which is open source and free.

Like all personal computers, the Pi does generate heat while in operation. For maximum operational reliability and lifespan, cooling for three chips on the Pi board must be provided and everything must be placed into a case which can allow for adequate convection cooling while also being transparent enough to RF energy for the Wi-Fi and Bluetooth radio modules to operate inside it.



The thermal image on the left shows a Raspberry Pi in basic operation with no cooling or heat sinking. The white spot over the CPU shows the temperature extremes reached by the silicon as it does it's work. Without removal of this heat the processor will slow its clock speed dynamically in order to limit operating temperature and avoid immediate damage. Higher temperature operation will lead to a shorter lifespan of the Pi. Two other chips on the board, the USB + Ethernet interface and the HDMI framer on the bottom of the circuit board, also generate heat during operation which must be removed. This is typically accomplished using a fan however a fan is not desirable in a high reliability embedded system.

The most basic approach to dealing with these heat issues is to install small aluminum heatsinks using thermal tape. The dimensions of these heatsinks are typically limited by height and thus surface area, in order to accommodate expansion "hat" circuit boards which sit above and parallel to the Pi PCB in what could potentially be a stack of circuit boards. Because a Pi occupies the bottom most position in a stack, the capacity to cool the CPU becomes greatly compromised without forced air. The IMS expansion hat architecture rotates the position of the expansion circuit board 180° relative to the expansion connector. This makes the pie case wider but it leaves the vertical space over the CPU and ethernet/USB controller free.



While the small heatsinks help they are insufficient for creating a high reliability embedded controller. With the height restriction removed we are free to add heatsinks with far greater heights and therefore far greater surface areas to distribute heat.

The case example on the right shows a passive design in which the heat of CPU and ethernet/USB controller is removed and dispersed into the case via two clearly visible heat pipes in the center. This example case is well-suited for hobbyists but it lacks space to include the additional interfaces and peripherals required by IMS. It also lacks the RF transparency required by the onboard Wi-Fi and Bluetooth interfaces to achieve optimum range.

A custom case which he uses this heat dispersal architecture is worthy of study but would require considerable machine work and be comparatively expensive. Until such time as the work to produce a milled aluminum case is deemed necessary, sufficient cooling for the CPU should be able to be achieved through the use of the high performance heatsinks shown to left which are available off-the-shelf from vendors such as Digikey and Mouser. The ethernet/USB controller produces less heat then the CPU albeit it can still get quite hot. This controller is packaged differently from the CPU and will not accept the same heat sink design used for the CPU however it may be adequately cooled using a taller version of the standard Pi solution applied with either thermal epoxy or thermal adhesive tape. The HDMI framer chip on the rear of the board also produces heat and may be most effectively cooled through the use of a large heat spreader with exposure to passive air convection.

Because of the unique requirements for this automation system, no Pi case currently on the market has been identified which is suitable. The lifespan of electronic components and their temperature is directly proportional. In almost all instances where the Pi is used as an embedded controller it is also equipped with a fan, however fans come with the inherent disadvantages of noise and wear which make them highly undesirable in an embedded controller. A passive heatsink with sufficient thermal mass is capable of keeping these chips cool, however the case these sinks sit within must also provide adequate convention airflow to maintain the operational efficiency of the heatsinks. Building the cases for the Pi nodes is actually one of the largest technical challenges of manufacturing the system.

Finally, a 5 volt power supply with sufficient capacity and a highly reliable power connection must also be provided. In the teaching wall this is accomplished with a 5 volt switching power supply which supplies a number of other functions with DC. In the center building module this may be accommodated with a plug in power supply or a quality commercial switching supply from a vendor such as Meanwell which also provides DC voltage to the ICE-9 modules distributed throughout the room.

All Pi based modules run from the exact same FLASH configuration in order to simplify firmware distribution. The IMS peripheral board paired with the Pi identities the desired functionality of that node to the OS during boot and loads operating software accordingly. Firmware is stored on 32GB Samsung PRO+ line microSD cards. The 32GB Samsung PRO+ is higher capacity than required for most uses today but was specifically selected in contrast to other lines and other densities in the same line based on testing from a number of sources. This particular microSD card demonstrates superior performance in terms of data transfer speed and therefore operation of the Pi. Should the firmware of any Pi based module become damaged, the **RCP1** may be used to restore a functional operating system on the corrupted card by inserting that card into a USB adapter and then booting that Pi system. When a secondary microSD card containing an operating system is detected at boot, that card is automatically checksummed. If the checksum is found to be in error, the card will be erased and a new copy of the operating firmware will be installed.

IMS embeds the Pi for three different uses:

The first is the **RCP1** or Remote control panel type 1 which is a Pi equipped with a 7 inch touch screen, LiFePO4 UPS, a CAN-bus controller, and a real time clock. This module runs Node Red software which is used for monitoring and control of building resources including HVAC, lighting, security, and also for logging environmental and power consumption data. It makes this data available in both raw and graphical form using a dashboard interface available both inside the room and anywhere on the Internet to those with the proper security credentials.

The second use of the Pi is in the **MC1** or Media Controller Type 1 which controls the presentation systems in a classroom or conference room configuration. Its hardware includes a Pi, a LiFePO4 UPS, a CAN-bus controller, and a real time clock. This pie is responsible for integration of all audio visual capabilities. It provides a universal text/video message board interface, a streaming audio receiver, a streaming video receiver, a video player, a slideshow player, a PowerPoint player, a dashboard interface to the building control systems, general web browsing, and a display for local weather station data.

Finally, in the **CLMB1** clock/message board configuration the Pi in tandem with an LCD monitor is used to provide a wall clock which may also be used for text or graphical messages or video streaming. For this use CAN-bus and a real time clock are unnecessary but a UPS is still required to prevent microSD card corruption. In the clock/message board configuration the pie is never writing files and it can obtain the real time over the network, removing the need for a local real-time clock in this module. Ultimately all modules which operate with the knowledge of real-time keep their internal clocks updated via network time services from the NIST atomic clock in Fort Collins, Colorado. This insures all nodes always maintain a synchronized time.

Software details go here…….

Raspberry Pi based nodes are responsible for:

Node Red - Room resource control and mappings
Node Red - Room energy management
Node Red - HVAC schedule
Node Red - Lighting schedule
Node Red - Environmental data logging
Apache - Web server for room dash board
Apache - Web server for room control panel
SQLite - Database services for data logging to USB drive in teaching wall
HDMI Video Message Board System with text, graphics, & video support
Streaming audio/video receiver for intercom
Streaming audio/video encoder/transmitter for intercom/monitoring
Mosquito - MQTT Broker
BACnet IP <-> MQTT Bridge
CAN-bus <-> MQTT Bridge
TCP/IP <-> CAN-bus Bridge
CAN-bus network time services
Class Clock

USB hosting of files on thumb drives for slide shows
Bluetooth communication with Apple TV to coordinate media mode switching
Bluetooth communication with remote controls
Camera interface (potential)

Multimedia System Design

The goal of IMS' multimedia system design is to provide a highly capable system with exceptional ease-of-use. This system is flexible enough to keep pace with evolving A/V standards while at the same time allowing for single button control from a user who wants to remain insulated from all operational details.

Presentation systems are evolving at a rapid pace. ICE-9 accommodates this rapid progression as well as the desire for a wide range of different customer configurations by providing a set of tools which can be used to integrate off-the-shelf A/V components and to control them in a way which is completely transparent to the user. Depending on the target audience, there may be an extremely wide array of different A/V configurations which are desired. The **SDIR1** Signal Director module simulates the operation of up to eight individual IR remote control transmitters, allowing a single queue from an application to trigger the **SDIR1** to issue any set of control commands necessary to properly configure all of the AV components in the system to a given state.

The **SDIR1** provides eight 3.5 mm TRS sockets and each of these sockets may be connected directly too a device to be controlled via a patch cord if that device has an IR input jack, or they may be connected to IR repeater LEDs adjacent to the receivers of the devices to be controlled. The SDIR1 also includes an output to control a solid-state relay to allow hard power down of all presentation system components for energy savings.

Several other modules including the **MIP1** input panel, **AMIX1** audio mixer, **ACP1** audio control panel, and **MC1** media controller round out of the building blocks for a presentation system.

Most of the higher level functions of ICE-9 are handled by either the **RCP1** Remote Control Panel or the **MC1** Media Controller module. The **MC1** module is primarily in charge of governing the multimedia systems in a room and also plays an active role in presentation by streaming video and or audio or presenting webpages through those systems. The **MC1** and the **RCP1** modules work in concert and share any operational information necessary to perform their tasks. This degree of integration allows a single button press to turn on monitors, configure video inputs, configure audio outputs, dim the room lights, darken the windows, set an initial volume for payback, and start playing a video.

Complete integration with a Bluetooth Remote control is also possible. The Apple TV remote is one such candidate.

All multimedia system components are supplied to power through a Brick Wall surge suppressor. Additional information on the Brick Wall device is presented in the next section.

IMS has multiple reference designs for presentation systems built from modular components. The most ornate of these designs includes two monitors and up to six video sources including two **MIP1** panel inputs, HDMI from the **MC1** Pi, Apple TV, Chromecast, and a classroom computer which may be a Mac or PC with an HDMI port. Each of the signal sources is fed into an HDMI splitter and the splitter outputs are distributed to two six input HDMI switches, one connected to each monitor. Both HDMI switch outputs as well as the Media Controller Pi's output are passed through audio extractors which have TOSlink optical outputs and the capability to decode 5.1 channel audio as a stereo signal. All three TOSlink cables from the extractors then feed into the **AMIX1** Digital/ analog audio mixer module. This allows the monitor's volume to be kept at zero with all audio handled by the **AMIX1**. If 5.1 audio is required, the volume of the extracted stereo signal can be lowered to zero well the volume on one of the monitors which is connected directly to a speaker system is raised. This allows 5.1 audio to be a transparent option requiring only the installation of additional speakers to support.

The **AMIX1** also provides several analog inputs to accommodate up to two wired or wireless microphone systems and utility audio from the **CLMB1** clock/message board module.

The **ACP1** audio control panel provides two rotary encoders for intuitive control of volumes in the system, one for media content and the other for microphones.

OR

INTERMODAL STRUCTURES

ICE-9

Modules:

7 / 10 / 17

Electrical Protection for ICE-9 and Presentation Systems

Building automation and A/V systems can represent a considerable investment. As electrical insurance for these systems, power is supplied via a Brick Wall surge protection system from Price Wheeler LLC. These unique devices limit input surges by dissipating excess energy in a shunted magnetic field. Typical surge suppression devices make use of limited lifespan components which absorb excess energy directly and are sacrificed during surge suppression, requiring subsequent replacement. The Brick Wall system uses both passive and active measures to limit surges however it contains no sacrificial components and does not require replacement even after repeated surges. The brick wall is integrated within the utility closet where it provides protection to the DC supply for the ICE-9 system as well as the presentation wall via the electrical distribution system. By mounting the suppression system at the point of power distribution, the physical length of the power cable between the utility closet and the A/V components serves as a time delay to give the active clamping circuitry inside the Brick Wall additional nanoseconds to operate and protect to those A/V components should an extreme voltage spike be encountered.

Depending on presentation system and HVAC configuration, it may be possible to include non-ICE-9 HVAC control systems (not including blower or compressor motors or heating elements) under the Brick Wall's protection umbrella.

BRICKWALL
NON-FAIL POWER QUALITY PRODUCTS

Electrical Distribution, Control, & Monitoring

To be written.

ICE-9 Modules:

Any building automation scenario maybe implemented using modular ICE-9 building blocks. Each of these building blocks is a self-contained computer based on an ARM Cortex processor which communicates over CAN-bus. Any number of modules may be interconnected through a CAN-bus infrastructure to meet the needs of the installation.
Module list as of 7/10/17:

Lighting Resource Modules:

LCP1	Light Control Panel Type 1 - Momentary switch actuated
LCP2	Light Control Panel Type 2 - Touch Panel with Glass controls
LDC1	Lighting Driver Controller for eight channels of 0-10V Analog or 10V PWM
SO1	Security / Occupancy Sensor
WCG1	Window Control Gateway Type 1 (for View window systems)
WCG2	Window Control Gateway Type 2 (for ??????? window systems)
IDMX1	Sky Illumination Sensor interface / DMX Gateway
SKY1	Sky Illumination Sensor / Weather Station Interface

HVAC Modules:

HVAC1	Heating Ventilation and Air Conditioning controller with sensor interfaces
THRM1	Wall Thermostat with temp & humidity sensor

Power Monitoring & Control Modules:

PM1	Power Monitor for DIRTT/Spider Agile Tech. modular power system
PMC1	Power Control & Monitor for lighting & HVAC

Presentation System Specific Modules:

ACP1	Audio Level Control
SDIR1	Signal Director IR Commander
MIP1	HDMI & Isolated USB input connectors with source switch
AMIX1	Audio Mixer with optical inputs

Pi Modules:

MC1	Media/Master Controller
CLMB1	Classroom Clock and Message Board
RCP1	Remote Control Panel

Support Modules:

RFG1	RF Automation Component Gateway
RFID1	RFID Receiver
JB1	Junction Box for interconnection (Passive)
HUB1	Quad CAN-bus Hub with isolation

ICE-9 Module:

LCP1

Light Control Panel Type 1 - Momentary switch actuated

The LCP1 module is intended for use in place of standard light switches. This module sits behind a standard Leviton Decora MODEL: 5657-2W dual momentary switch and sends commands to the Lighting Driver Controller.

Up to 4 switches in one box may be accommodated by a single ICE-9 module.

Additionally the LCP1 has an input for a reed sensor for door closure detection and a connection for addition of an RFID reader for use in access control and identification.

Multiple Zone installation: The LCP1 includes a 16 position rotary switch which is used to select the zone of desired control if more than one zone is used in a room network. In most installations this switch will be left set to "0", its default setting.

Operation: This module supports two momentary switch inputs called "UP" and "DOWN", which are connected to a DPST Center-off momentary switch. Switch closure is monitored for "tap" and "hold" operation. A "tap" is defined as a press of less than 1 second.

tap UP	tells the lighting controller to ramp up brightness to 100%
hold UP	tells the lighting controller to gradually increase brightness as long as the switch is held
hold DOWN	tells the lighting controller to gradually increase brightness as long as the switch is held
tap DOWN	tells the lighting controller to ramp down brightness to minimum and then to power down the driver

ICE-9 Module:

LCP2

Light Control Panel Type 2 - Touch Control with Window Control

The LCP2 module is intended for use as a master light control in classrooms or anywhere a touch control is desired. This module also includes five window control settings and sends commands to Lighting Driver Controllers as well as any Window Control Gateways.

Multiple Zone installation: The LCP2 includes a 16 position rotary switch which is used to select the zone of desired control if more than one zone is used in a room network. In most installations this switch will be left set to "0", its default setting.

Operation: This module is integrated with a standard light switch faceplate. It features touch contacts for turning lights off and on as well as a slider region, allowing for dimming. It also features a set of six buttons for controlling windows. Tint levels of 0%, 25%, 50%, 75%, or 100% may be selected directly or the windows can be set to track the lighting automatically via an "auto" button. LED feedback is provided for the window level setting.

ICE-9 Module:

LDC1

Lighting Driver Controller Type 1 - Eight channels of 0-10V Analog or 10V PWM

The LDC1 module responds to commands from lighting control panels and outputs either 0 to 10 volt analog or 10 volt PWM signals for controlling standard LED driver modules. Digital outputs are also provided to enable solid state power relays for the drivers. Eight analog outputs and eight digital outputs are provided.

Default Operation: In default operation this module will respond to all commands issued by lighting control panels in the same zone. Under the control of Node Red this module may be reconfigured to follow a separate control program. In this way lighting systems are functional immediately after power is applied and before node red has started to operate, at least to the point of providing basic functionality. Once noted red comes online it issues a command on the CAN-bus which causes the LDC1to listen to message boxes populated by Node Red rather than the default ones. At this point name much more ornate control program can take over.

Multiple Zone installation: The LDC1 includes a 16 position rotary switch which is used to select the zone of desired control if more than one zone is used in a room network. In most installations this switch will be left set to “0”, its default setting.

Installation: This module is designed to sit in the utility closet adjacent to the LED drivers and solid-state relays. Terminal barrier strips are provided to connect to the control leads of the LED drivers. An RJ-45 patch cord is used to interconnect to the LDC1 and the solid-state relay module

ICE-9 Module:

SO1

Security & Occupancy Sensor Type 1 - Passive IR

The SO1 module includes a Passive IR sensor to watch the room for movement as well as an additional proximity sensor input which may optionally be connected to an external sensor, and an output for optionally driving a solid state relay to operate an audio annunciator drive such as a bell or buzzer. This sensor is used in the same manner as a standard PIR occupancy sensor. Mounting locations would typically include the corners of the room. Movement data from these sensors maybe utilized by lighting, security, and environmental control systems simultaneously.

Multiple Zone installation: The SO1 includes a 16 position rotary switch which is used to select the location in the room.

Installation: This module is designed to go into a wall mounted to junction box. Pluggable terminal barrier strips are provided to connect an additional external proximity sensor for security purposes and/or solid-state relay module to drive an audio annunciator.

ICE-9 Module:

WCG1

Window Control Gateway Type 1 (for View window systems)

The WCG1 module responds to commands from ICE-9 lighting or window control panels and translates those communications into messages for View's proprietary window controllers on a second CAN-bus. The WCG1 includes the support components required to deliver 24VDC power to the window controllers via view's custom cable. The DC voltage is provided by an external power supply.

Default Operation: (clear)

Multiple Zone installation: The WCG1 includes a 16 position rotary switch which is used to select the zone of desired control if more than one zone is used in a room network. In most installations this switch will be left set to "0", its default setting.

Installation: This module is designed to sit in the utility closet adjacent to the Power supply for the windows. Pluggable terminal barrier strips are provided to connect to the DC supply and an optional solid-state relay to control power to the supply.

ICE-9 Module:

WCG2

Window Control Gateway Type 2 (for ???????? window systems)

The WCG2 module responds to commands from ICE-9 lighting or window control panels and translates those communications into messages for ???????'s proprietary window controllers on a second CAN-bus. The WCG2 includes the support components required to deliver DC power to the window controllers via ???????'s custom cable. The DC voltage is provided by an external power supply.

Default Operation: (clear)

Multiple Zone installation: The WCG2 includes a 16 position rotary switch which is used to select the zone of desired control if more than one zone is used in a room network. In most installations this switch will be left set to "0", its default setting.

Installation: This module is designed to sit in the utility closet adjacent to the Power supply for the windows. Pluggable terminal barrier strips are provided to connect to the DC supply and an optional solid-state relay to control power to the supply.

ICE-9 Module:

IDMX1

Sky Illumination Sensor Interface / DMX Gateway

The IDMX1 module provides a pair of lighting related interfaces. It provides an input for a four quadrant sky illumination sensor to be used with automatic window systems and it also provides a DMX output for controlling architectural lighting.

The SKY1 sky illumination sensor is mounted on the structure's roof and tied into the IDMX1 via a RJ-45 Cat 5 cable. In a multiple story structure, window controllers on lower floors may make use of a sensor on an upper floor via the network. In addition the sky illumination sensor may be fitted with other weather sensing components, turning it into a complete weather station with anemometer, wind direction, air temperature, humidity, barometric pressure, Lux level and rain gauge. If any of these other sensors are present the IDMX1 will except their data and deliver it to the proper message boxes for weather data.

This module also includes a DMX interface, the industry standard for controlling theatrical and architectural lighting. The DMX interface Controls up to one universe or a maximum of 512 data channels. This should provide for more than enough capacity to control any reasonable amount of architectural lighting around a structure.

Because both of these interfaces are external they are dramatically more susceptible to damage and for this reason both the input and output channels of the IDMX1 are optically isolated.

Installation: This module is designed to sit in the utility closet adjacent to the LED drivers and solid-state relays. Terminal barrier strips are provided to connect to the control leads of the LED drivers. An RJ-45 patch cord is used to interconnect to the LDC1 and the solid-state relay module

ICE-9 Module:

SKY1

Sky Illumination Sensor with Weather Station Interface

The SKY1 is a four quadrant sky illumination sensor for use in the automatic control of window systems. The SKY1 is typically mounted on the structure's roof and tied into the IDMX1 via an RJ-45 Cat 5 cable. In a multiple story structure, window controllers on lower floors may make use of a sensor on an upper floor via the network. In addition the sky illumination sensor may be fitted with other weather sensing components, turning it into a complete weather station with anemometer, wind direction, air temperature, humidity, barometric pressure, Lux level and rain gauge.

Installation: This module is designed to on the roof of the structure. An RJ-45 patch cord is used to interconnect to the SKY1 and IDMX1 module.

ICE-9 Module:

HVAC1

Heating Ventilation and Air Conditioning controller Type 1 with sensor interfaces

The HVAC1 module is a complete network connected and totally programmable 2 stage HVAC control system with scheduling and an interface to a number of environmental sensors as well as an RS-485 interface and a second CAN-bus interface dedicated to interfacing with HVAC components such as servo operated dampers. It only lacks a local user interface which he is provided by a THRM1 module.

Sensor inputs include intake plenum temperature and humidity, carbon dioxide, particulate count, output plenum temperature and humidity, and external supply temperature and humidity.

The **HVAC1** module works in tandem with the **THRM1** wall thermostat module to form a complete system. The THRM1 places a temperature and humidity sensor midway between the floor and the ceiling for a more ideal temperature reference as well as providing the user interface. Any number of **HVAC1** modules may be driven by a single thermostat module. In more complex configurations multiple thermostat modules many operate on a single HVAC module which is tied to servo operated duct dampers and a single HVAC unit.

Internally the **HVAC1** emulates the business end of a two stage dry contact thermostat and provides up to seven programmable relays which can be connected directly to conventional two-stage heating and cooling systems involving a wide range of technologies. All outputs are programmable in order to adapt to any potential HVAC system. An RS-485 interface and a second CAN-bus interface dedicated to interfacing with HVAC components allow additional networked air handling components to be integrated with basic system operation.

If desired, a small LCD and push button interface may be added to this module for a user interface which is kept locked away in the utility closet. In such a case the temperature sensors in the intake and output plenums could be used to accommodate the lack of a typical style wall thermostat.

Multiple Zone installation: The **HVAC1** includes a 16 position rotary switch which is used to select the zone of operation if more than one zone is used in a room network. In most installations this switch will be left set to “0”, its default setting.

Installation: This module is designed to sit in the utility closet. Pluggable terminal barrier strips are used to connect to the HVAC equipment.

ICE-9 Module:

THRM1

Wall Thermostat Type 1 with temp & humidity sensor

The **THRM1** is a basic wall thermostat containing a high resolution temperature and humidity sensor.

The objective of this module it Is to provide an intuitive Wall thermostat Interface to the HVAC system while simultaneously not utilizing an expensive standard product which may be a target for theft.

When approached within one meter, the THRM1 display will show both the present and desired set temperature. Up and down buttons allow the user to select the desired temperature. A Mode switch is used to select heating only, cooling only, ventilation only, or system off modes.

Multiple Zone installation: The **THRM1** includes a 16 position rotary switch which is used to select the zone of desired control if more than one zone is used in a room network. In most installations this switch will be left set to "0", its default setting.

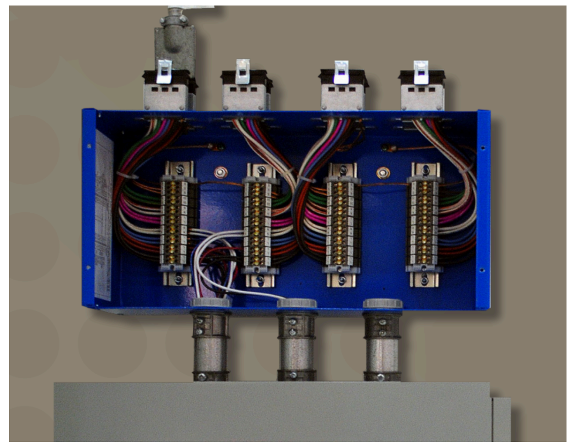
Installation: This module is designed to mount on the wall half way between the floor and ceiling and maybe located anywhere on the CAN-bus.

ICE-9 Module:

PM1

Power Monitor Type 1 for DIRTT/Spider Agile Tech. modular power system

The **PM1** module is a high granularity power measuring module for the spider agile technology power distribution systems used in DIRTT interiors.



The Spider Agile Technology power distribution "Panel Manager" box as shipped contains a series of the DIN rails and terminal blocks for interconnecting Spider's modular socket system with supply wiring fed from circuit breakers in the distribution panel. The PM1 replaces these terminal blocks and DIN rails with a circuit board containing current monitoring sensors and terminal blocks. An isolated interface to CAN-bus makes the consumption data available to the RCP1 where it is stored in a database locally or are transmitted to a cloud service.

Each hot lead from the breaker panel runs through a 30 amp capable Hall effect sensor.

ICE-9 **Module:**

PMC1

Power Monitor & Control **for lighting & HVAC Type 1**

The **PMC1** module is a voltage and current consumption monitor for tracking power use by the entire modular structure with three main subsystems. The first subsystem tracks the voltage supply and current consumption of the entire modular structure at the utility entrance by using current transformers and voltage dividers. The second subsystem monitors the consumption of the individual infrastructure circuits such as lighting and HVAC. The final subsystem provides solid-state relays for energizing HVAC and lighting systems to de-energize the lighting and HVAC systems when not in use for extra power savings.

Power data is presented to the CAN-bus through an isolated link for protection.

ICE-9 Module:

ACP1

Audio Control Panel Type 1

The **ACP1** Audio Control Panel module is a face plate style module with two rotary encoders for controlling the volume of both presentation program material and a wireless microphone system. Rotary volume controls provide an intuitive interface for controlling system volumes.

Level feedback is provided via LEDs.

Pressing an encoder mutes that channel.

Multiple Zone installation: The LDC1 includes a 16 position rotary switch which is used to select the zone of desired control if more than one zone is used in a room network. In most installations this switch will be left set to "0", its default setting.

ICE-9 Module:

SDIR1

Signal Director IR/RF Commander Type 1

The **SDIR1** Signal Director Type 1 is a complete subsystem for integrating complex media installations with ICE-9 to allow for transparent control. This module emulates up to eight parallel IR remotes for configuring consumer A/V equipment according to queues from higher level devices. This module also performs several additional functions such as interfacing with the audio output mixer for presentation systems and providing support for up to two **MIP1** HDMI/ isolated USB input panels.

The SDIR1 contains an output for driving a solid state relay to control AC power to the multimedia equipment. When not in use the multimedia components may be powered down to reduce state current consumption.

Multiple Zone installation: The **SDIR1** includes a 16 position rotary switch which is used to select the zone of desired control if more than one zone is used in a room network. In most installations this switch will be left set to "0", its default setting.

Installation: This module is designed to sit in the teaching wall amidst the devices to be controlled. An RJ-45 patch cord is used to interconnect to the **SDIR1** and each of up to two **MIP1** modules.

ICE-9 **Module:**

MIP1

HDMI & Isolated USB input connectors with source switch Type 1

The **MIP1** is a faceplate based module which provides HDMI and isolated USB inputs to the presentation system. It also provides a single pushbutton source selection interface and a series of LEDs to indicate the source selected. This module works as a direct slave device to the signal director module **SDIR1** and up to two **MIP1** modules are supported by each **SDIR1**.

The HDMI ports passively feed all signals to a second HDMI connector at the rear of the module. From there, a standard HDMI patch cord brings the signal to a splitter so that it may be delivered to both monitors. The hot plug to detect input from the HDMI port is buffered and delivered to the signal director so that it may automatically configure other pieces of the system appropriately when an HDMI signal is presented.

The USB inputs provide an optically isolated and electrically hardened input for memory sticks and similar devices which may be safely presented to the Media Controller Pi. Nefarious devices exist on the market which deliver very high energy discharge into USB ports for the purpose of destroying the hardware they are a part of. It is inevitable that publicly accessible USB ports will see abuse which may extend all the way to the use of devices created for technical vandalism. Accidental static discharge can be just as dangerous to electronics and the isolation provided by this module also protects against that.

A single pushbutton allows an operator to sequentially select an input device. Message board, Apple TV, Chrome-cast, Computer, and external input LEDs show which source is active.

Plugging an external input into the HDMI jack will cause automatic selection of that external input on both monitors if two monitors are used.

The source may also be selected via ICE-9 so that inserting a USB drive with pictures on it can cause a Pi to instruct both monitors to select the Pi as an input as it launches a slideshow program.

Installation: This module is designed to sit in the utility closet adjacent to the LED drivers and solid-state relays. Terminal barrier strips are provided to connect to the control leads of the LED drivers. An RJ-45 patch cord is used to interconnect to the LDC1 and the solid-state relay module

ICE-9 Module:

AMIX1

Audio Mixer with optical inputs Type 1

The **AMIX1** is a custom audio mixer which accepts inputs from a number of sources and direction from the signal director **SDIR1** module, and provides both analog and TOSlink outputs to connect to a power amplifier.

TOSlink inputs are fed from each monitor and the **MC1** Media Controller Pi to the mixer in parallel with analog inputs from a presentation microphone system and an external input where are they are all mixed to provide a stereo output.

TOSlink is used as the primary audio source interconnect to eliminate the potential of ground loops and to maintain audio at the highest quality possible.

Outputs are muted at both start up and shut down allowing the mixer output to be fed directly to a power amplifier with only a volume control to set maximum output level.

Installation: This module is designed to install inside the presentation wall next to the other AV components.

Inputs:
TOSlink monitor 1 extracted audio
TOSlink monitor 2 extracted audio
TOSlink MC Pi
TOSlink Clock Pi
TOSlink Class Computer
TOSlink External Input
TOSlink UniSound
3.5mm TS FM1 (mono)
3.5mm TS FM2 (mono)
3.5mm TRS

ICE-9 Module:

MC1

Media/Master Controller Type 1

The **MC1** media controller module is a Raspberry Pi based multipurpose node which is responsible for integration of all audio visual capabilities as well as being an active part of the presentation systems. It provides a universal text/video message board, a streaming audio receiver, an audio player, a streaming video receiver, a video player, a slideshow player, a PowerPoint player, general Web browsing, a Web dashboard interface to the building control systems for displaying current conditions and logged data, and a display for local weather station data.

The **MC1** runs a Node Red script which is responsible for integration of the system's AV components to allow for easy customization. It is also responsible for running a number of multimedia applications. The capabilities of this node are entirely based in software and this software may be upgraded either locally or remotely (if permitted via security) at any time to enhance existing features, to add new features, or to provide customization.

The **MC1** also supports the USB ports contained in the **MIP1** input panels. When a USB thumb drive is inserted in one of the USB ports in the presentation wall the **MC1** looks for files to display on that drive and launches the appropriate application.

Multiple Zone installation: The **MC1** includes a 16 position rotary switch which is used to select the zone of desired control if more than one zone is used in a room network. In most installations this switch will be left set to "0", its default setting.

Installation: This module is installed in the presentation wall where it can receive convection cooling. It receives DC power from an external power supply module which also powers other AV system components. It receives connections to both ethernet and CAN-bus, and it provides video and audio output via HDMI. This module contains a Bluetooth transceiver and should be oriented such that the Bluetooth antenna has the most advantageous coverage of the room.

ICE-9 Module:

CLMB1

Classroom Clock and Message Board Type 1

The **CLMB1** is a network based Monitor Driver which may be used to display a clock or other important data. This module is based on a raspberry pie three model B and the display program is based on HTML5. In default operation a locally generated clock is shown. When commanded via Ethernet, the **CLMB1** will display the contents of any other webpage in order to serve as a message board or other information annunciator. This may include video and or audio streaming as well as text. The CLMB1 may also be used as a stopwatch or a countdown timer.

Installation: This module is designed to be mounted adjacent to a monitor in the uppermost wall section of the teaching wall. It connects to DC supply, Ethernet, and outputs HMDI to the monitor. Monitor resolution is 1920 x 1200.

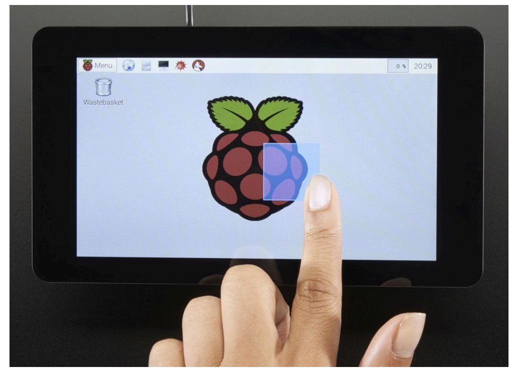
Examples of random digital clock faces are shown below. The clock face is drawn using HTML 5 and thus it is 100% customizable.

ICE-9 Module:

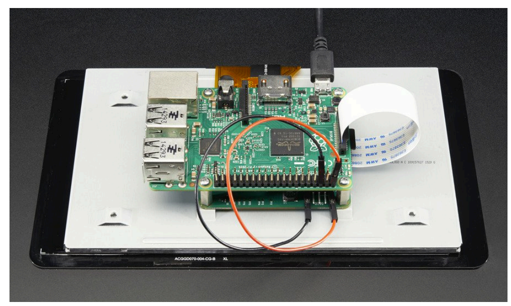
RCP1

Remote Control Panel Type 1

The **RCP1** is a remote control panel equipped with a 7 inch Touch screen. This module is based on the Raspberry Pi 3 and is responsible for running the Node Red building automation program which controls lighting, HVAC, Power consumption monitoring, and environmental data logging. It is also responsible for serving the web based dashboard, serving the web-based Control Panel, and routing all system information to ethernet or BACnet IP for remote monitoring and control. This panel would typically be installed inside the utility closet in a classroom scenario or in that general area in an office scenario.



The **RCP1** is a complete Linux computer running the Raspbian distribution of Debian Linux. IMS adds the touch screen, a built-in UPS based on lithium iron phosphate battery technology for extreme safety and reliability, a CAN-bus Interface, and a real time clock to create the finished hardware.



The **RCP1** provides complete Control of all room functions as well as a dashboard to view energy and environmental sensor data via the touchscreen LCD interface.

This Raspberry Pi is responsible for the following functions:

- Node Red - Room resource control mappings
- Node Red - Room energy management & data logging
- Node Red - HVAC schedule
- Node Red - Lighting schedule
- Node Red - Environmental data logging
- Apache - Web server for room dash board
- Apache - Web server for room control panel
- SQLite - Database services for data logging to USB drives
- Mosquito - MQTT Broker
- BACnet IP <-> MQTT Bridge
- CAN-bus <-> MQTT Bridge
- TCP/IP <-> CAN-bus Bridge
- CAN-bus network time services

ICE-9 Module:

RFG1

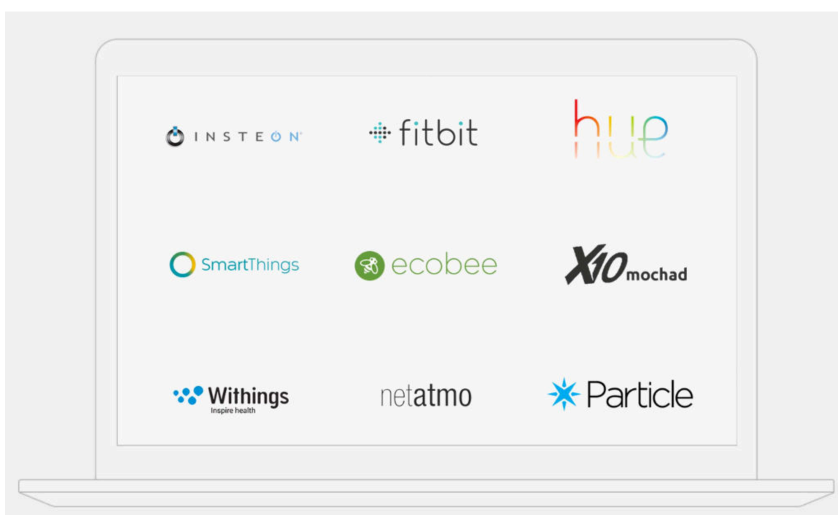
RF Automation Component Gateway Type 1

The **RFG1** is an automation gateway between ICE-9 and 315/433MHz RF consumer building automation components from vendors such as Samsung and Phillips HUE lighting. The RFG1 is able to work with a wide variety of devices from multiple vendors simultaneously. All operation is software based and may be updated as new vendors become available.

The initial release of this peripheral board contains 315MHz and 433MHz RF modules to interface with many existing building automation components sold at Home Depot, Lowe's, Target, Walmart, and IKEA among other vendors. While these RF devices are not principal components of the ICE-9 system, they do allow end-users to integrate additional functionality at the consumer level. This degree of openness in the integration of automation components with the users of the structure leads to much greater user participation in the energy conservation strategies. Consumer level automation products such as HUE light bulbs and Samsung's SmartThings automation components are supported out of the box.

Additional RF systems such as ZigBee 802.15.4 and Z-Wave may be added in the future via the addition of RF modules and software for those standards.

Multiple Zone installation: The **RFG1** includes a 16 position rotary switch which is used to select the zone of desired control if more than one zone is used in a room network. In most installations this switch will be left set to "0", its default setting.



ICE-9 Module:

JB1

Junction Box Type 1

The **JB1** is a passive junction box which provides interconnections for CAN-bus, Ethernet, and speaker wiring. The **JB1** provides a convenient way to pre-wire a center module and all of its subsystems while providing a consistent place and method for adjacent building modules to interconnect. The **JB1** is also used to inject 5VDC power into the CAN-bus network.

There is significant potential to integrate the HUB1 CAN-bus hub in this enclosure.

ICE-9 Module:

HUB1

Four Port CAN-bus Network Hub Type 1

The HUB1 is a four port CAN-bus hub which is used to connect from two to four CAN-bus segments into a single logical network. Each CAN-bus segment is limited to a maximum of approximately 50 devices and 200m of cable. Should the capacity of a single segment become a limitation, the HUB1 can be used to add additional wire segments, multiplying capacities by the number of segments in use.

Operation is completely transparent and there are no settings, either software or hardware.

There is significant potential to integrate this device with the **JB1** junction box type 1.

This device may be constructed so that it contains two pairs of ports which are optically isolated from each other in order to avoid ground loops. This permutation provides two local buses as well as a pair of ports behind an isolation barrier for implementation of a site backbone. This could be useful for adding out buildings to a design while using a minimum of infrastructure.

Installation: Pluggable terminal barrier strips are provided to connect DC power injection.

Components: **AMIS42770ICAW1G** - On Semiconductor

Building an automation and control system using ICE-9 modules

A quick-start:

Building an automation and control system using ICE-9 modules, a quick-start:

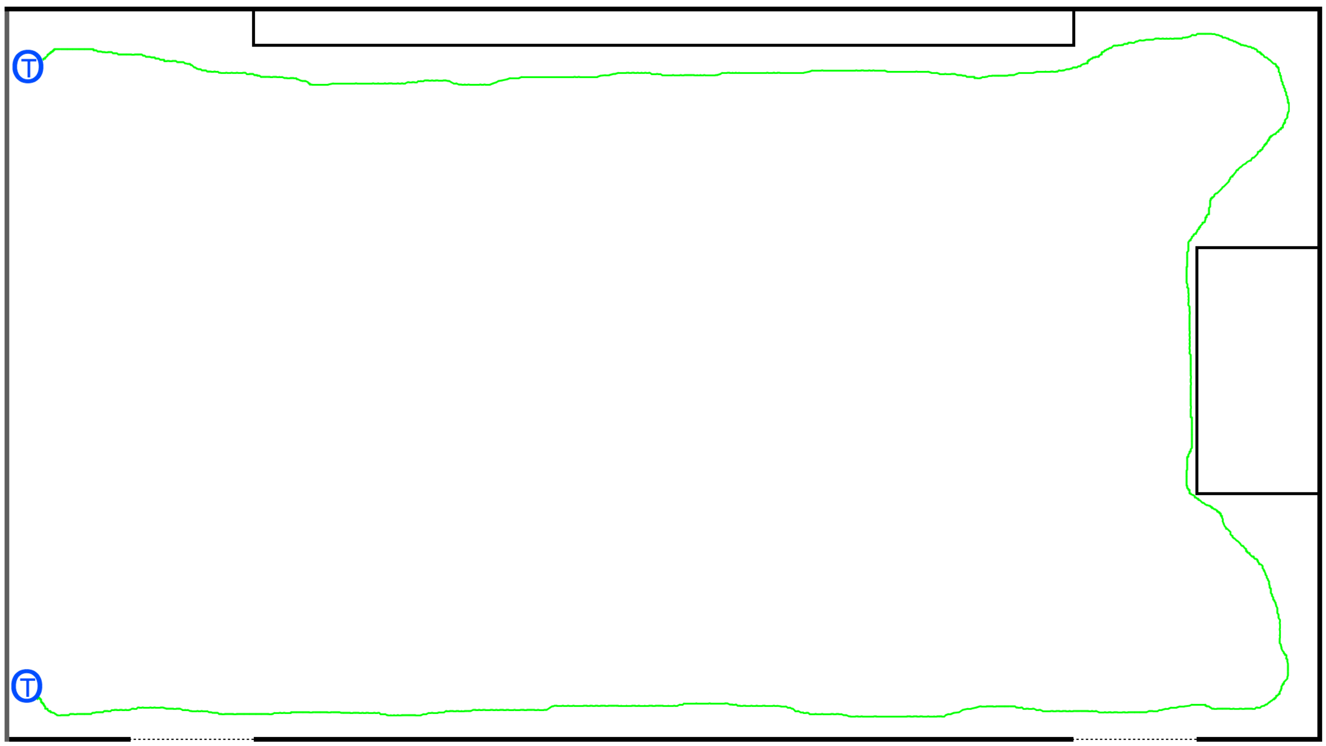
This section describes the components used and the process of building modular controls using the ICE-9 modular building automation and control system.

ICE-9 is a distributed building control system, meaning each of the components in the system which performs work contains built-in intelligence. Each major building control function is implemented as a separate module. Using this architecture, any building control system maybe easily sculpted using a series of off-the-shelf components. Lighting, HVAC, power monitoring, environmental monitoring, and security modules all interconnect using standard RJ-45 network cables. Reconfiguring a system is as simple as disconnecting unneeded modules or adding new modules to address new requirements.

A single ICE-9 network segment typically covers a single room but may also include adjoining spaces.

Multiple rooms are linked together via Ethernet allowing arbitrarily large campus installations to interoperate down to the individual resource level.

Slide One: The Backbone

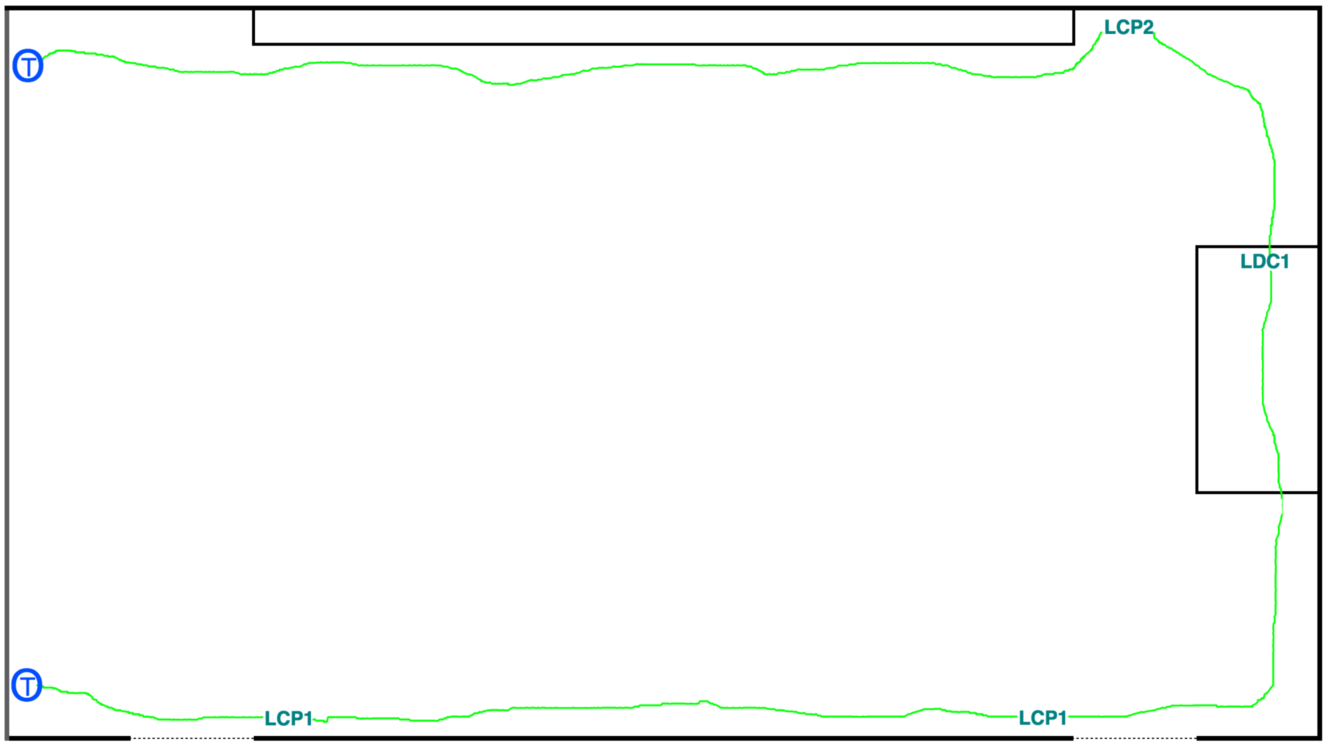


Let's start with the network backbone, shown above in green and its end of cable terminators, shown in blue. ICE-9 uses the CAN-bus network to connect all of the modules in a given room. CAN-bus is short for Controller Area Network-bus. It was developed by BOSCH and it's the same network system used within cars, factories, refineries, industrial robots, airliners, and spacecraft use to interconnect sensing and control systems. CAN-bus has become the world's undisputed champion network type for industrial control systems.

CAN-bus implementations are designed to use different signaling rates to trade off between latency and maximum cable distance. ICE-9 uses a 500Kbp/s signaling rate to accommodate a maximum of 60 devices and up to 200m of network cable length while keeping latency so short as to be unnoticeable. This bus uses a daisy chained topology where are each node is wired in series. Each end of the wire is terminated with a terminating resistor, marked here as a "T" within a circle. If more than 60 network devices are required in a given design, a four port CAN-bus hub allows for the connection of up to 4 CAN-bus segments, supporting a total of up to 240 devices. A typical classroom implementation with rich multimedia features requires approximately 20 ICE-9 devices. A floor of a larger office building configuration might require more than 30. RJ-45 junction boxes are provided at intermodal module junctions to facilitate simplified installation on-site.

The general idea is that each room or section will receive its own local CAN-bus network. These local networks are then interconnected via ethernet. Using a series of smaller interconnected networks provides greater fault tolerance.

Slide Two: Adding lighting components



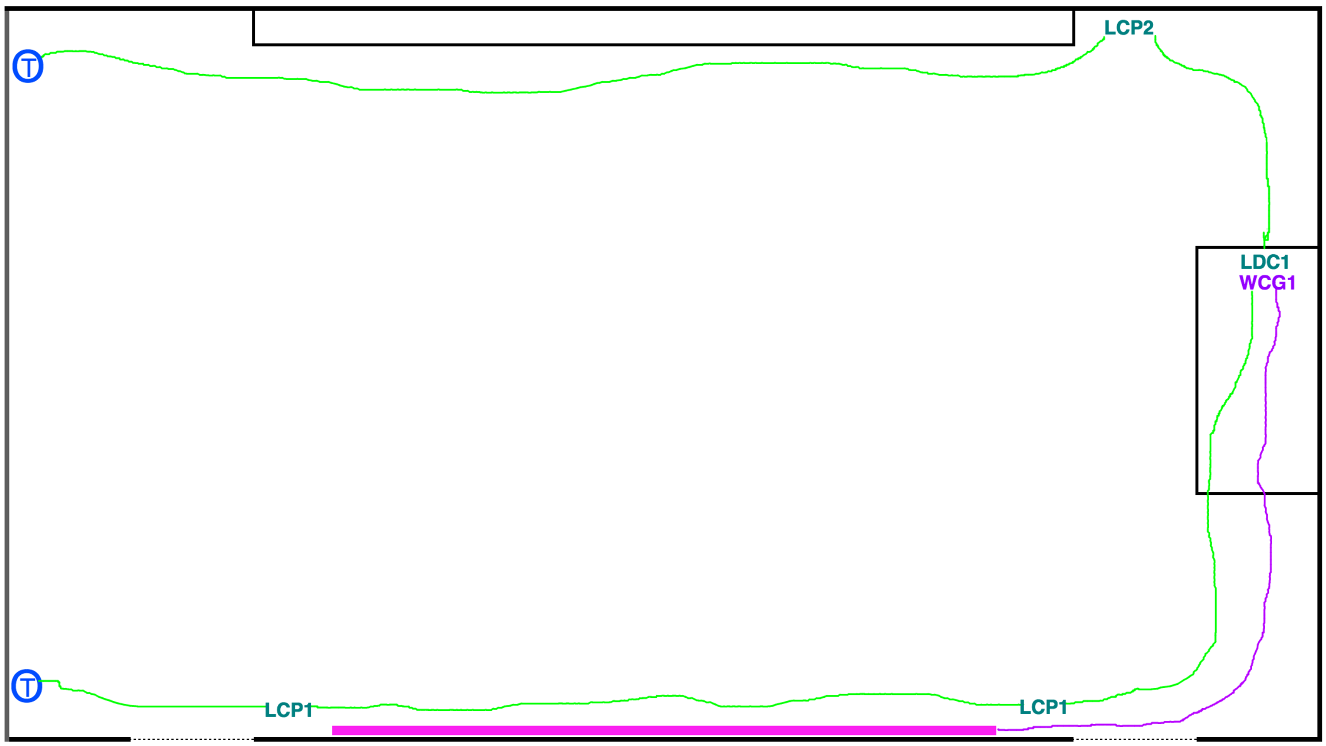
Now let's add the lighting components. Along with the corridor wall we now add two simple **LCP1** light switch control units. Along the back wall we add a more complex **LCP2** lighting control panel with touch sensitive dimming. In the utility closet we add a **LDC1** LED driver controller module.

The two **LCP1** switches in the front use off-the-shelf Levaton Decora style Center off momentary switches to provide off, on, dim up, and dim down functions while being completely intuitive to operate and resistant to physical damage.

The more advanced **LCP2** panel in the rear of the room uses a touch sensitive surface to provide even more control over lighting levels. This more complex panel may also provided controls to affect automatic window systems bringing room luminance controls into a single location.

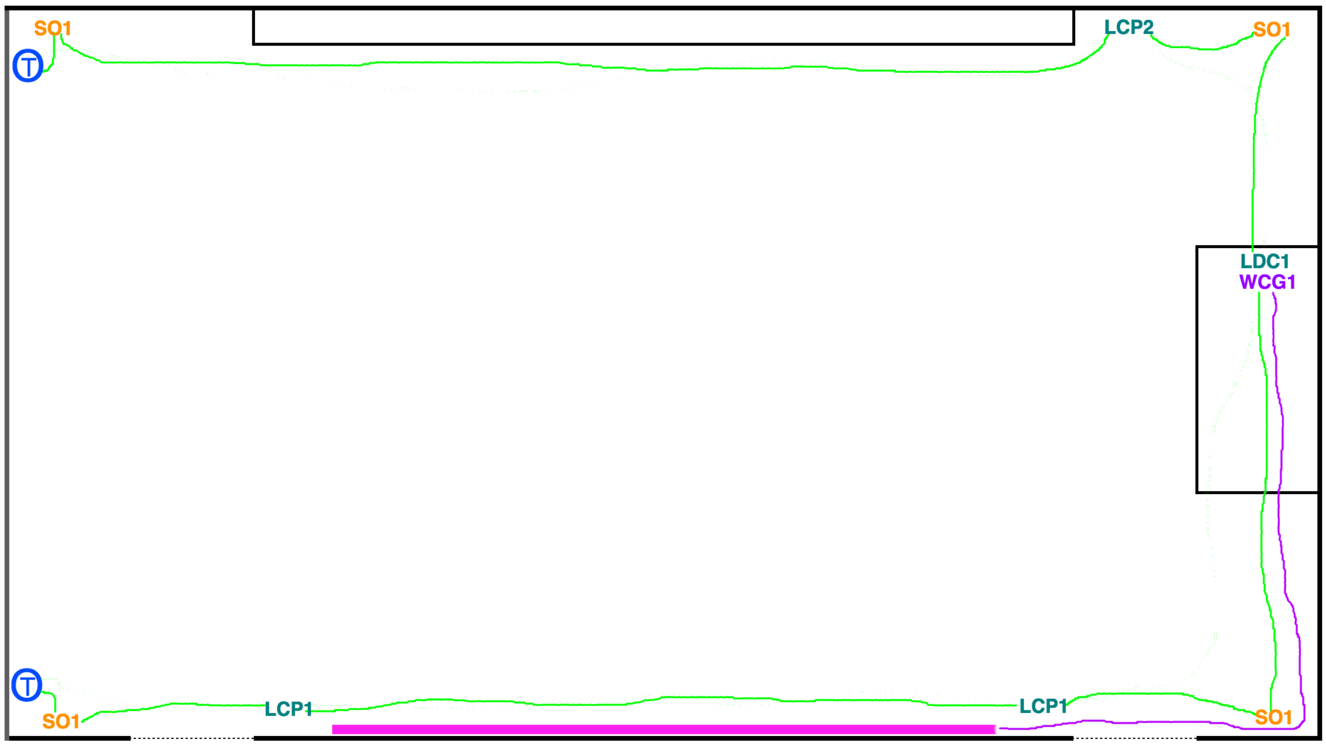
In the utility closet the **LDC1** LED driver controller module receives level control commands from any of the three controls. In response the **LDC1** generates 0-10V analog signals to operate off-the-shelf high quality LED driver modules. This system provides complete flexibility. As LEDs evolve the drivers will continue to accept 0-10V control signals for the foreseeable future. If it becomes necessary to support new technology, the controller can be upgraded as an individual component to provide more advanced system capabilities. Each of these modules contains a 16 position rotary switch allowing for up to 16 zones of control within a “room”. In almost all installations, setting of these switches will be unnecessary because only a single zone will be used. The two simpler light switch control units along the corridor wall also contain inputs for door open switches to monitor room usage, and optionally an RFID reader.

Slide Three: Adding tint-able window support



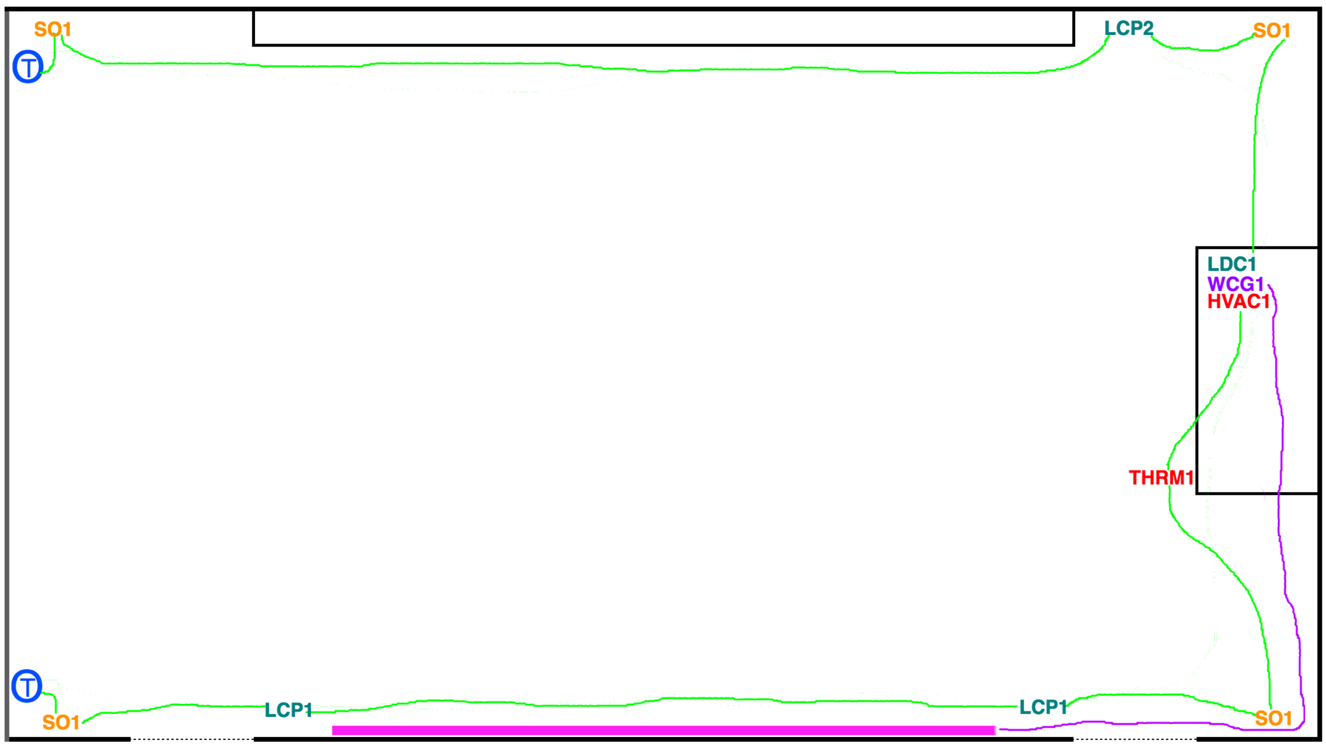
If electronically controlled View brand window systems are utilized, a **WCG1** window system gateway module is installed in the utility closet and then connected to the windowpane controllers. In this example the windows generally take their commands from the **LCP2** complex lighting control panel at the back of the room. Now a single button press on the lighting control panel can be used to affect both the windows in the lighting systems.

Slide Four: Occupancy sensors



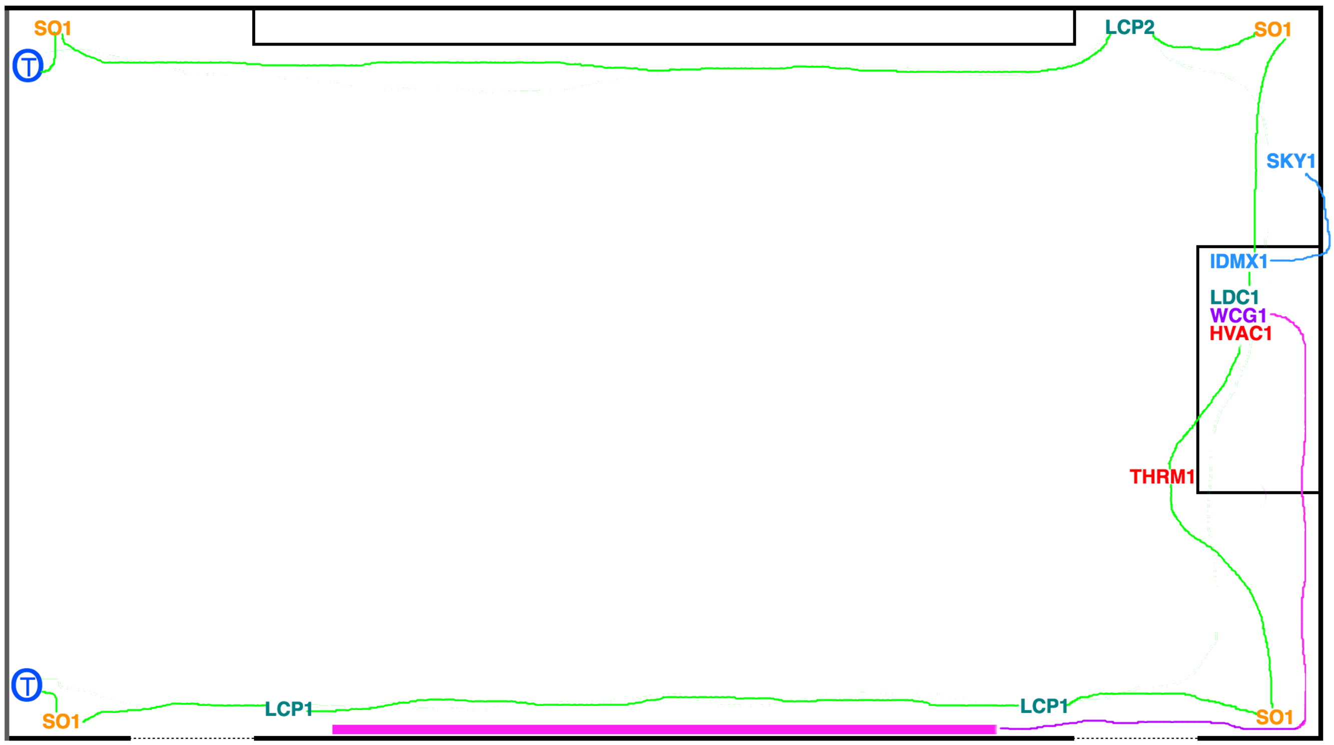
Occupancy information is vital for both energy control systems and for security purposes. Here we add an occupancy sensor into each corner of the room. Using multiple sensors provides better coverage. During usage hours these sensors can be utilized to control lighting. At other times the sensors may be used to provide security information. Each of these sensor modules is capable of watching a passive IR sensor in the room as well as two additional sensors which may be mounted outside the room. These modules are also capable of operating a solid-state relay to sound an alarm klaxon or bell.

Slide Five: HVAC Control



HVAC control is provided through an **HVAC1** module located in the utility closet. This module is essentially the brains of a high end network thermostat which provides both two-stage heating and cooling functions. A custom wall thermostat module talks to the **HVAC1** through the CAN-bus creating a complete subsystem. This approach reduces the cost of the wall thermostat and turns it into something which will not be the target theft even though the system possesses the same capabilities as a $250+ dollar unit. The HVAC module also plays host to a series of sensors. The wall thermostat provides both temperature and humidity sensors while additional temperature and humidity sensors are mounted in both the intake and output plenums from the HVAC system as well as in the external air supply plenum. Additional sensors such as particulate, carbon dioxide, and carbon monoxide monitor air quality. Because placement is crucial to the operation of sensors, additional sensors may be added to the system anywhere simply by connecting them to the ICE-9 CAN-bus.

Slide Six: Adding the sky illuminance sensor

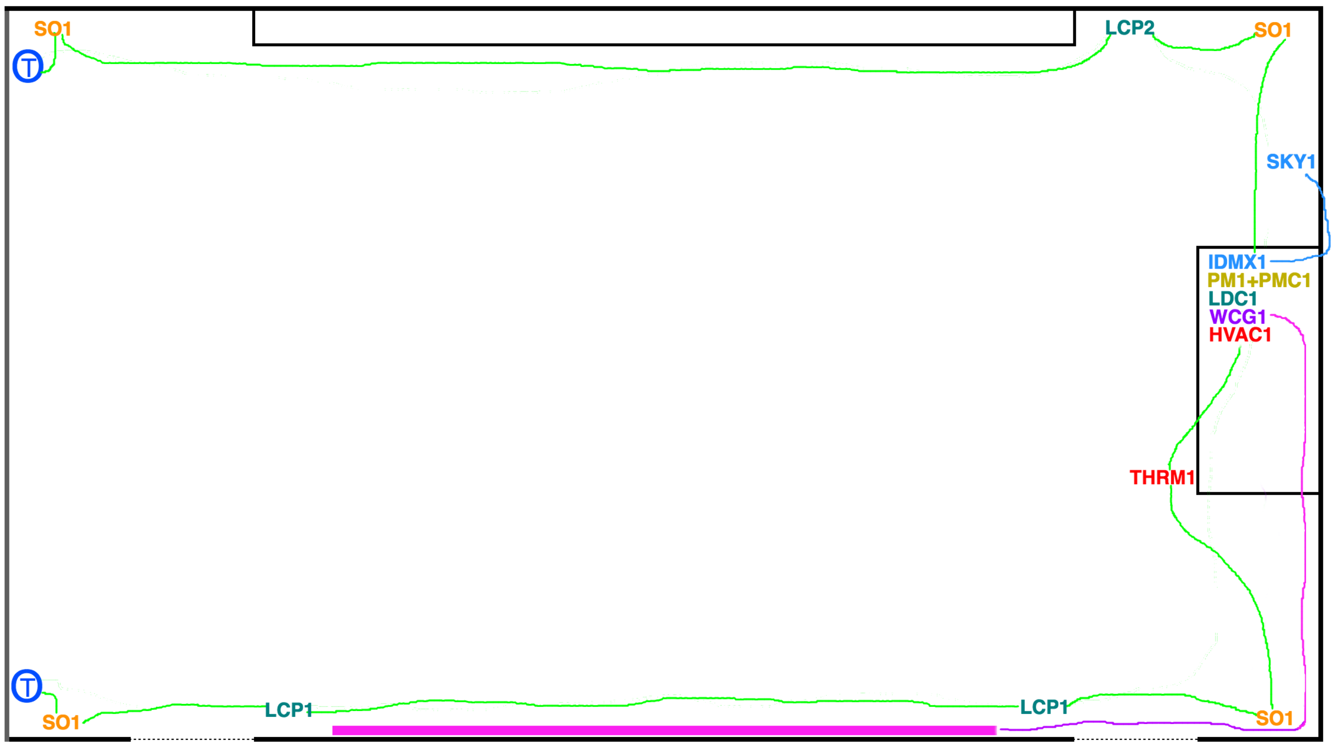


Automated window systems may utilize a **SKY1** sky illuminance sensor to determine automatic level settings. This sensor must be mounted on the roof with a clear view of the sky and being external to the intermodal structure makes this illuminance sensor more vulnerable to electrical disruption so it receives its own dedicated interface rather than extending the internal CAN-bus to the roof.

This slide adds the **SKY1** sky sensor and the **IDMX1** module to receive data from the sensor with its optically isolated input which provides protection to the internal CAN-bus network components. The **IDMX1** module also provides an isolated DMX512 protocol output which may be used to drive exterior architectural lighting systems.

The **SKY1** luminance sensor module may be equipped with a connector to accommodate a basic WeatherStation unit consisting of wind direction and speed, temperature, humidity, barometric pressure, and precipitation. The ability to connect to a WeatherStation is a byproduct of having plenty of available I/O lines available at the relatively simple illuminance sensor.

Slide Seven: Power Monitoring & Control



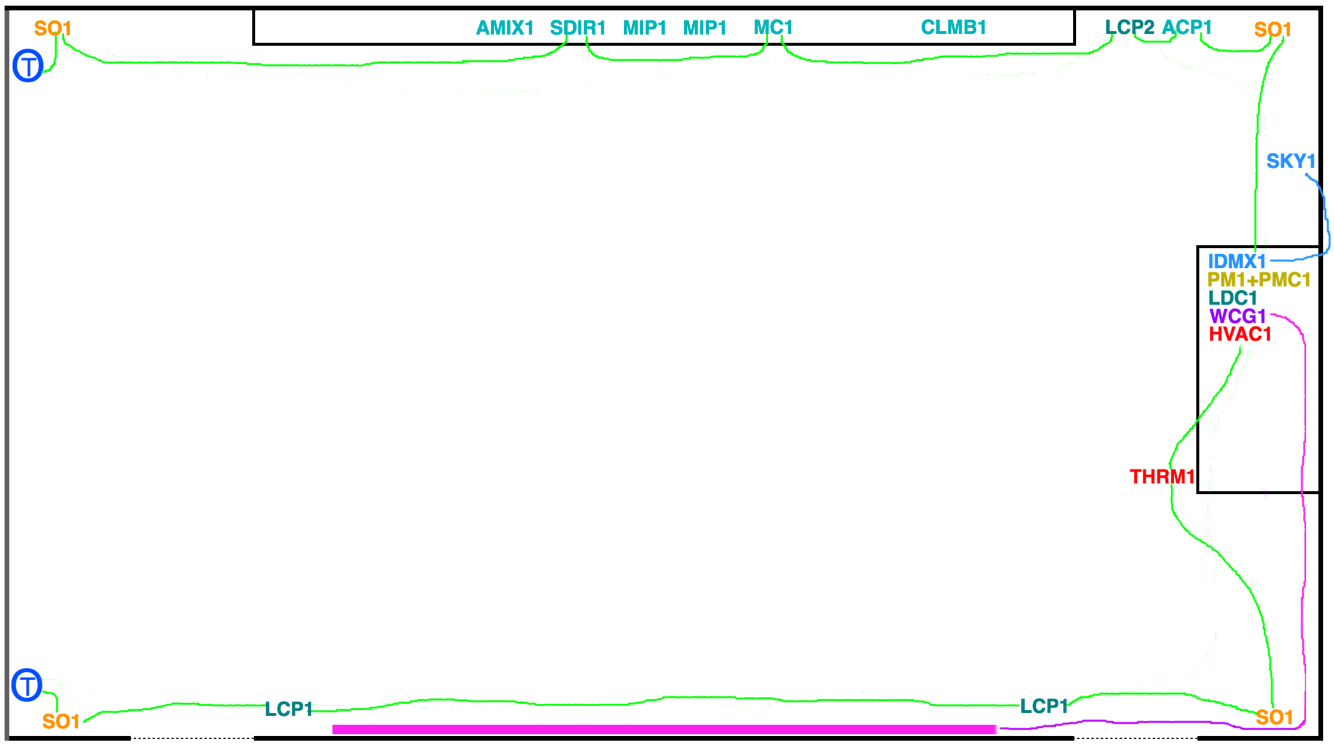
Power monitoring and control functions are provided by the **PM1** & **PMC1** modules.

The **PM1** installs inside the modular power distribution box and monitors the current consumption on each individual branch circuit, providing both current usage and historical usage data.

The **PMC1** performs power monitoring and control functions for infrastructure functions such as lighting and HVAC. When lighting levels of 0% are selected, the **PMC1** De-energizes the LED driver modules to save additional power. If desired, a hard power-down capability may also be applied to HVAC components.

The **PMC1** may also be used to provide a master power switch to all presentation wall components. Alternatively, power control for presentation wall components maybe located within the presentation wall where the **SDIR1** can be responsible for controlling the power state.

Slide Eight: Presentation Systems

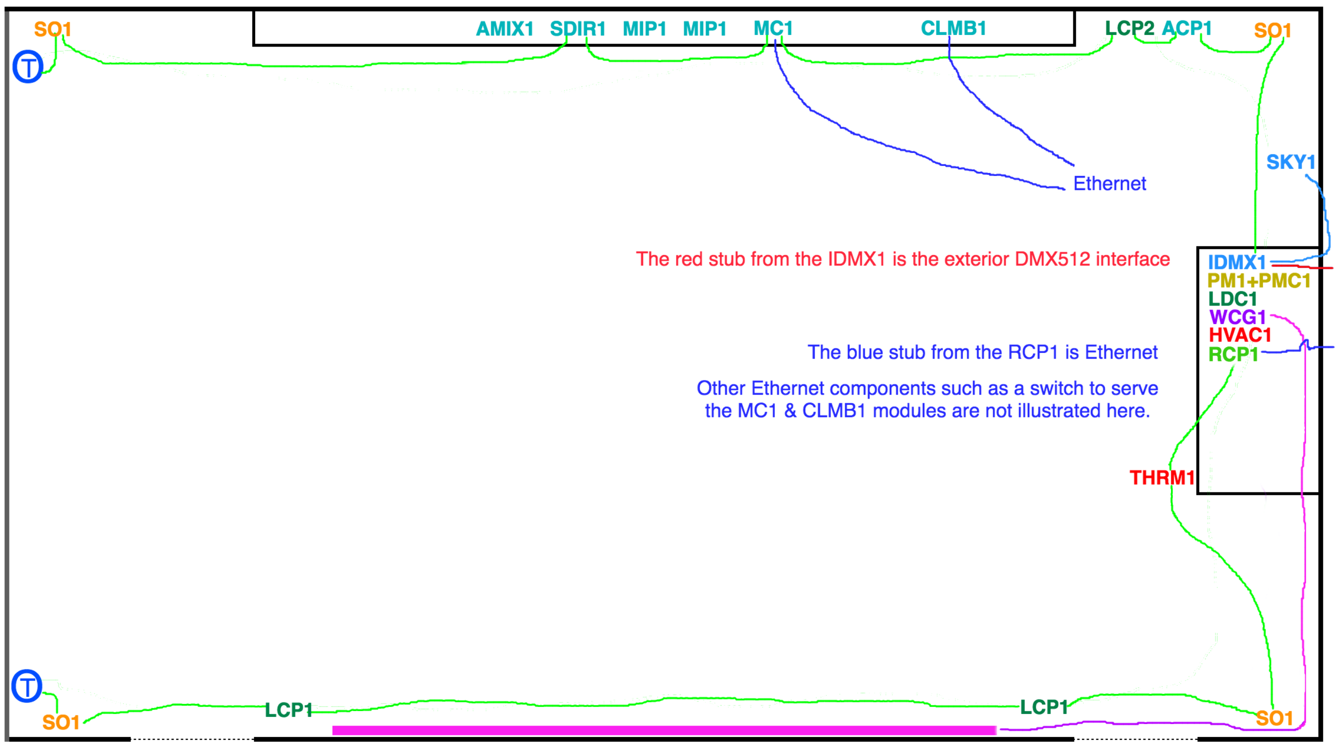


In ICE-9 systems, the presentation system is built from a series of modules operating in concert with consumer or professional A/V components which are equipped with IR Remote control capability. ICE-9 modules including the **SDIR1** Signal Director, **MIP1** input panel, **AMIX1** audio mixer, **ACP1** audio control panel, and **MC1** media controller round out of the building blocks for a presentation system.

As you can see, not all these modules are connected to the CAN-bus. The **AMIX1** receives control information from the **SDIR1** and routes the outputs of multiple A/V components to a single amplifier and set of speakers. The **MIP1** input panels also connect directly to the **SDIR1** for control operations. On the other hand the **ACP1** audio control is on the CAN-bus and may be located anywhere in the room.

Also shown in this diagram in the CLMB1 Clock/Message Board which is not connected to CAN-bus.

Slide Nine: RCP1, Node Red, and external networking



The **RPC1** Remote Control Panel serves several functions including running Node Red, bridging the CAN-bus to ethernet, providing protocol conversion for other automation standards, and it provides a touch screen LCD interface which serves as the master control panel for system automation functions.

The **RCP1** may be located anywhere in the room. It requires connections to both Ethernet and CAN-bus in addition to 5 V power. For additional security in a classroom or publicly accessible installation, the **RCP1** may be locked in the utility closet, in office scenarios it may be more desirable to leave this node in an exposed and accessible location.

ICE-9 System Classroom Component Example: (Bottom Floor)

Corridor Wall ICE-9 Modules:

SO1	Security / Occupancy Sensor
LCP1	Light Control Type 1 - Momentary switch
LCP1	Light Control Type 1 - Momentary switch
SO1	Security / Occupancy Sensor

Center Section ICE-9 Modules:

JB1	Junction Box (passive)
RCP1	Remote Control Panel
WCG1	Window Control Gateway Type 1
HVAC1	Heating Ventilation and Air Conditioning controller
THRM1	Wall Thermostat - connects to HVAC module
LDC1	Lighting Driver Controller
IDMX1	Illumination / DMX Architectural Lighting Gateway
PM1	Power Monitor for Spider Agile Tech. modular power system
PCM1	Power Control & Monitor for lighting & HVAC

Teaching Wall ICE-9 Modules:

SO1	Security / Occupancy Sensor
LCP2	Light Control Type 2 - Touch Panel with View Glass controls
ACP1	Audio Level Control
CL1	Classroom Clock and Annunciator Board
MC1	Media Controller
SD1	Signal Director IR Commander
SO1	Security / Occupancy Sensor
MIP1	HDMI & Isolated USB input connectors with source switch
MIP1	HDMI & Isolated USB input connectors with source switch
MIX	Audio Mixer with optical inputs

Additional components are used in the Long Beach configuration example which communicate via Ethernet:

Router	Provides IP mapping to the external world
Switch	8 port Fast Ethernet Switch for internal distribution
AccessPoint1	Wireless Access Point
AccessPoint2	Wireless Access Point (optional - required by some Districts)
Teacher's PC	Computer for use by teacher. May be PC/Mac/Chrome/Linux/etc.
AppleTV	Provides screen sharing from iPads, serves as video hub
Chrome-Cast	Provides screen sharing from Chrome books, serves as video hub
SpareJacks	Ethernet and AppleTV USB jacks in cabinet

ICE-9 System Office Component Example: (Top Floor)

Corridor Wall ICE-9 Modules:

SO1	Security / Occupancy Sensor
LCP1	Light Control Type 1 - Momentary switch
LCP1	Light Control Type 1 - Momentary switch
SO1	Security / Occupancy Sensor

Center Section ICE-9 Modules:

JB1	Junction Box (passive)
RCP1	Remote Control Panel
HVAC1	Heating Ventilation and Air Conditioning controller
THRM1	Wall Thermostat - connects to HVAC module
LDC1	Lighting Driver Controller
IDMX1	Illumination / DMX Architectural Lighting Gateway
SKY1	Sky Illumination Sensor / Weather Station Interface
PM1	Power Monitor for Spider Agile Tech. modular power system
PCM1	Power Control & Monitor for lighting & HVAC

Teaching Wall ICE-9 Modules:

SO1	Security / Occupancy Sensor
CL1	Classroom Clock and Annunciator Board
SO1	Security / Occupancy Sensor

Compatibility with devices from other ecosystems

Of the distinguishing characteristics of ICE-9 is it's almost unlimited degree of adaptability. So long as a communications channel is available, this system is capable of accepting almost any input, output, sensor, or actuator device.

A large ecosystem of devices is available for environments such as Apple's HomeKit and one example of a desirable device from this world is the Bluetooth based security lock for doors. Because these devices operate over Bluetooth it is possible to pair them with ICE-9 instead of their originally intended environment.

Many other automation systems exist as closed ecosystems with a central hub. In some cases ICE-9 is able to completely replace the functionality of the hub, making use of system modules as if they were native ICE-9 components. In other situations the automation hub may be connected to ethernet as in a typical installation and it used as an integrated adjunct to ICE-9.

The Amazon echo can be integrated to provide voice control of ICE-9. This interface is accomplished through the magic of Node Red.

Basic home automation components from systems such as IKEA's Trådfri and Samsung's SmartThings may be easily integrated into a Node Red flow.

This architecture allows for a considerable degree of customization by end users and encourages participation in energy conservation.

Glossay

Node Red Open Source software originally developed by IBM's Emerging Technologies Group and now the basis of industrial automation products such as IBM's Bluemix and AT&T's Flow. Node Red allows complex systems to be programmed, deployed, and maintained using an object oriented drag and drop visual interface.

CAN-bus Controller Area Network. The dominant technology used to connect subsystems in industrial automation. CAN-bus was originally developed by BOSCH for automobiles but it's now utilized in everything from industrial robots to elevators to jetliners to NASA spacecraft.

JSON JavaScript Object Notation is a lightweight data-interchange format. It is easy for humans to read and write as well as for machines to parse and generate. It's based on a subset of the JavaScript Programming Language, Standard ECMA-262 3rd Edition - December 1999

JavaScript Often abbreviated as JS, JavaScript is a high-level, dynamic, weakly typed, object-based, multi-paradigm, and interpreted programming language. Javascript is the language that runs all dynamic web pages on the web.

Node.js Node.js® is a JavaScript runtime built on Chrome's V8 JavaScript engine. Node.js uses an event-driven, non-blocking I/O model that makes it lightweight and efficient. Node.js' package ecosystem, npm, is the largest ecosystem of open source libraries in the world.

V8 V8 is Google's open source high-performance JavaScript engine, written in C++ and used in Chromium, Node.js and multiple other embedding applications. V8 implements ECMAScript as specified in ECMA-262 and runs on Windows, Mac OS X, and Linux systems. V8 can run standalone, or can be embedded into any C++ application. V8 compiles and executes JS source code, handles memory allocation, and garbage collects objects it no longer needs.

MQTT Message Queue Telemetry Transport or MQTT is a machine-to-machine (M2M) connectivity protocol originally developed by IBM's Emerging Technologies Group and designed as an extremely lightweight publish/subscribe messaging transport. It is useful for connections with remote locations where a small code footprint is required and/or network bandwidth is at a premium. MQTT has found wide adoption for communicating sensor data in industry, healthcare, and home automation.

Raspberry Pi The Pi is a single board Linux operating system and ARM processor based computer originally designed for the educational market which now enjoys a high degree of success in a large number of industries as an embedded controller.

Teensy The Teensy is a very small format embedded ARM processor based computer in the form of a small core module with robust I/O capabilities. Code for the teensy can be written in C, assembly, or with the Arduino integrated development environment. Each Teensy module contains an integrated USB programmer, allowing for easy firmware upgrades order customization to be applied in the field.

DMX512 A serial bus standard used in the lighting industry for control of everything from simple dimmers too complex theatrical stage effects. DMX512 has emerged as a worldwide standard for both indoor and outdoor effects lighting control as well as for architectural lighting.