PWGSC/RPB

Personal Environmental Controls Design Guidelines

PEC

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Personal Environmental Controls Guidelines

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1. Introduction

Environmental Controls, including lighting and Heating Ventilation and Air Conditioning, HVAC, have been around for decades but until recently, have not had a wide spread acceptance into the workplace environment. The reasons have included costs, maintenance, complexity, issues with reliability, commissioning and little proof of the claims of energy savings and increased productivity. Due to these factors, most large scale controls projects have only included large zone or entire building systems control. Lighting control, daylighting control and mechanical or HVAC control were installed, programmed and operated separately. In the world of base building lighting controls, this has basically meant that the lighting system acted like a giant egg timer, turning lights on and off as per building use schedules. This is status quo but offered very little flexibility or energy savings.

Today, the demand for controls has increased, with the environmentally enlightened criteria and focus of building owners, facilities and asset managers and project managers. This demand has had a twofold effect; it has increased the level of research and technology development, by manufacturers and the related lighting and HVAC industries and reduced the component and installation costs. At the same time, the value of the benefits associated with lighting controls; energy savings, demand responsiveness, organizational productivity, reduced costs and reduced waste management have continued to be quantified and to rise.

This guideline will provide design, planning, technical and installation information as well as cost, benefits and how current recommended practices, regulations and Green programs can be used and what they mean, to a successful project.

1.1 Overview

Personal Environmental Controls, PEC, are defined as an integrated control system and strategy that allows an individual to control their ambient lighting and ventilation at their workstation. This allows individuals to satisfy their own personal requirements and preferences for lighting level and thermal comfort. Personal controls can also be separated to provide only lighting control or ventilation control. Although these may be referred to as personal environmental controls they are in fact personal lighting or personal ventilation controls.

There are three basic types of controls included in Personal Environmental Controls;

1) Lighting controls, that include, base building lighting zones that are sized and operated independently from daylighting, occupancy sensors, daylight sensors and personal control at the workstation,

2) Mechanical controls that include base building zones that are sized and operated independently from lighting zones, room control and workstation control over the thermal environment and air quality, and

3) Personal environmental control that is the integration of individual lighting and ventilation control at the workstation or office. These also include the daylight harvesting and occupancy recognition.

1.2 Energy Savings & Benefits

Over the years Public Works and Government Services Canada, (PWGSC), the Light Right Consortium, Lawrence Berkley Labs, NRC and other researchers such as Dr. David Wyons have studied the benefits of controls. These studies have included energy savings, demand control and ancillary benefits such as, comfort, satisfaction, individual performance and organizational productivity. These laboratory and field studies have indicated that energy savings for lighting controls ranges from 15% for daylight harvesting to 75% for the PEC integrated system, to the workstation.

Studies conducted by the Light Right Consortium, Dr. Wyons, NRC, B.C.Hydro and PWGSC, under the Program for Energy Research and Development, PERD, have indicated that there is a direct correlation between occupant satisfaction with their workplace environment, lighting and ventilation. In a study conducted by Chin, C. & Hetherington, W., PWGSC 2001, $_{(1),}$ regarding occupant satisfaction with personal control over ventilation and the number of trouble calls, they found that there was a savings of $112,950.00 and an increase in environmental satisfaction from 80 to between 90 and 99%. Research conducted by the Light Right Consortium in 2006,$_{(2),}$ indicated that those individuals with increased environmental satisfaction over lighting also identified having an increased job satisfaction. This may not seem like much until you look at one of the variables that an organization measures their productivity; the costs of attraction and retention. Losing an employee costs an organization approximately twice the employee's annual salary to find a replacement.(3) This does not include the additional loss of corporate memory, networks that can streamline processes and connect people to access the correct process or information faster or the cost of the additional burden others take on having to do the lost employee's work.

An additional study by the National Research Council of Canada, NRC, has indicated that personal control improved task performance and also had a positive impact on participants ability to focus when undertaking cognitive tasks.(4)

Additional benefits to an organization are related to the Operation and Maintenance of the building or complex. Due to the ability of the environmental control system to be programmed for load shedding during peak power demand periods and continued dimming due to daylight harvesting and occupancy sensors, as well as personal preference, there is also the potential savings in regard to maintenance and waste management. Dimming extends the life of lamps and ballasts, therefore reducing the personnel time replacement costs. This also has an impact upon the waste management for the building. Extend life means that there is less lamp, ballast or mechanical components being disposed of into landfills etc.

In general, research in this area has found:

- **45% energy savings from a workstation specific lighting design**
- **37% energy savings from occupancy sensors in every workstation**
- **15% energy savings from daylight harvesting**
- **10% energy savings from ventilation control in every workstation**
- **11% energy savings from personal control in every workstation**
- **An additional 10% energy savings for combined control strategies during peak power demand**
- **Reduced O&M costs, including Trouble Calls and Churn**
- **Increased environmental satisfaction and job satisfaction**
- **Increased task performance and cognitive focus**

Additional benefits that have not been quantified beyond specific case studies are:

- **Reduced waste management and related costs due to dimming and control**

- **GhG emission reduction due to reduced energy consumption and power demand**
- **Potential for clients to remain long term in a building**

2. Understanding the Issues

Lighting and HVAC building automation control has become the standard for all large commercial buildings and there is an increase in the use and requirement for different controls strategies. New standards such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers - ASHRAE 90.1 2004 recommends using smaller zones and control strategies to reduce power allowances for lighting and HVAC. The same is true for the lighting industry recommended practices, Illuminating Engineering Society of North America, IESNA, RP-01-04, Leadership in Energy and Environmental Design, LEED and the BOMA Go-Green programs. These standards and guidelines are responding to societal and organizational demands to increase energy savings, reduce the carbon and environmental footprint of the client organization, maximize utility incentives and provide more occupant control.

2.1 Issues and Recommendations

There are a number of issues that need to be taken into consideration when designing a PEC system. The following are a list of issues to be aware of and recommendations:

- Integration: Know your existing system intimately, have up-to-date technical as-builts available. Know the scope of your project and the essential features CTR-Link - Affordable Industrial Ethernet Hubs, Switches, and Media Converters and benefits you are expecting to have available at completion.

- As built documents, and detailed description of the functions of the lighting and HVAC equipment under control. Don't rely upon guessing equipment capabilities; research these thoroughly to understand the specifics of how each component can be operated and their design range.

- BACnet version, including functions and services available in the installed system. Be aware of operational behaviour,

- Consider requirement differences between versions. Often features between versions are not backward compatible.

- Not all products are equal; check OWS functions thoroughly. Many features may be proprietary in nature and may not have full functionality with other products. For instance, most products have binary inputs but not all products include provision to use the inputs for status indication of binary outputs. This can be worked around by writing logic for this indication. Some additional equipment or programming may be required for usage. Analog values have some unique but similar situations. These may not be familiar to the integrating contractor.

- Have a good appreciation of your need to collect and store data from trends or energy totalization. If you are working in a campus environment where a large number of points will be in the system (10,000 or 1,000,000, this is quite possible in multi-story buildings or airports), storage requirements will quickly exceed today's OWS systems capacity. It is likely that an IT consultant would offer solutions with longer life and resources to make a more useful data set.

- Trending is a very useful function. Vendors have many variations for implementing trending and longer term data storage sometimes called historical trends. Be sure the overall system will meet all your expectations. BACnet defines the transport of trend data but does not make any effort to define how the data is presented to user or the user interaction to retrieve data from the systems. Only after using a system will these differences become apparent. DALI transports and stores the trending of data for energy and lighting component status and failure, but does not yet incorporate HVAC to this level.

- Energy totalization features and capacities vary from product to product, including where the values are stored (low level controller, building controller or OWS/Server) within the system.

- System graphics displayed on a user's OWS display will exhibit differences in the way menus are accessed and the interaction with points on the OWS screen. Generally speaking it is preferable that only one product be used for interaction at one location (where multiple OWS locations are deployed).

- Be prepared to challenge your installing contractor regarding placement of equipment and sensors (location and type). Sensor type, often are selected for contractors advantage and may not be installed in the best location for accurate measurement. Averaging sensors will provide better information for mixed air applications (and proper mounting in air stream) than a single point, in particular for larger duct sizes (over 10 sq ft duct area).

Experience has shown that each item in the list has been part of the reason for poor system performance and erroneous data being provided or observed. The old adages of "garbage, in garbage out" holds very true in this situation. The data reliability is only as good as the accuracy of the measurement of the fluids and their behaviour in the systems being monitored.

3. Basic Principles

3.1 Design and Planning

There are a number of variations of integrated control systems;

- Lighting and HVAC
- Daylighting and electric lighting
- Occupancy sensors and HVAC
- Occupancy sensors and lighting
- Lighting, daylighting, occupancy and HVAC (PEC)

These all perform specific functions, on/off, dimming, occupancy detection, air flow regulation, scheduling, daylight recognition and harvesting, demand control and preference control. It is only the inclusion of all lighting and HVAC controls in one integrated system that provide the culmination of these functions. It is also only the integration of these controls that provides the entire range of individual comfort, satisfaction and energy savings.

3.1.1 Determining Controls Selection and Strategies

There are a variety of control strategies that should be looked at for every project especially those considering personal control. For example, personal control may not be necessary or appropriate for some applications or projects. First the project team needs to determine which strategy fits their client's budget, energy savings and O&M criteria. When developing a controls strategy, there are a number of different types of control or combinations of sequences that can be used. Ancillary factors such as end user satisfaction and the client's organizational productivity impacts must be considered. How the client needs are addressed will impact the specific requirements and design concepts the project team implements.

For example, a commercial building that is only considering a retro-fit rather than a renovation project, may only want to look at daylight harvesting and/or occupancy sensors to increase energy savings. This does not provide the ancillary benefit of increased satisfaction and performance of the employees, but it may address reduced energy and O&M. This ensures that the energy and environmental factors are being addressed at little cost to the overall project. However, there are new digital ballast control options that can provide individual control at only a few hundred dollars per workstation. What would not be wise to consider is a retro-fit of an HVAC system for personal control, unless the project manager can assure the clients that there will be little disruption to their work environment

On the other hand, if a renovation project is being considered, with a larger budget, a more integrated approach of personal control for lighting and/or ventilation to the workstation should be considered. The additional costs for this type of system is approximately $1,200.00 per workstation, (5); a cost that could easily be recouped due to the reduced first cost of luminaires, lamps, ballasts, reduced energy costs annually and reduced annual waste management costs. Although the organizational benefits would be more difficult to quantify until after the installation, these savings could be used in the Life Cycle Costs for the next project.

3.1.2 DALI

DALI stands for ***D**igital **A**ddressable **L**ighting **I**nterface* and is a protocol set out in the technical standard IEC 60929.

It has been approved as the standard ballast protocol of the North American controls industry and has been adopted by most ballast manufacturers. It is BACNet compatible but this does not mean one should assume that all of the protocols for each system are fully interoperatible.

The DALI system allows the interconnection of a number of different devices, such as various types of sensors, switches, lamps and ballasts. Each device should be verified that it has been identified by the manufacturer, as DALI compatible. This should be verified during project planning.

Currently, DALI is a dedicated protocol purely for lighting control. This means that DALI cannot be used to control other systems such as HVAC local control functions. The manufacturers are working on being able to integrate the controls capability with HVAC and other building systems and services. It is expected that this will be achieved within the next year or two. It is also recommended that the project manager request that the consultant or contractor verify the level of integration available before moving forward with a project.

When considering DALI, ensure that the project manager and the technical team understand all of the different DALI components and operation of each. Not all components are DALI compatible or directly compatible so it is important to determine what the operational, scheduling and trending requirements are for each component and sensor. It may be decided to use a non DALI sensor, but the contractor should provide verification in the form of documentation from the manufacturers how they should be integrated and what the reliability issues may arise.

As with any equipment of this nature, it should also be noted that the information on websites is not very complete, so, make sure all documentation comes from the specific manufacturer for each of the products including drawings, wiring diagrams and ballast addressing and scheduling is received from the contractor for the specific project.

DALI is effective for providing individual control of on/off dimming programming to each ballast and for getting feedback regarding faulty light sources. This makes it very useful to use together with building automation systems where remote supervision and service reports are required. It also makes it a valuable tool for providing personal control to each workstation.

System Description

Each ballast in the DALI network has its own individual address. This makes it possible to communicate directly to the components in the setting and on site verification of the communication loop during commissioning and set up.

It is possible to control several different groups of fittings or loop, through one pair of control cables. The DALI system is programmed to provide information to be sent to and from the ballasts and controllers. This allows for feedback on the condition of the ballast. In this way, each ballast can transmit information about:

- Whether the light is switched on or off,
- The preset light level,
- Ballast condition.

The cabling consists of a simple two wire cable and one for communication. Once the system is installed and configured, any change to the functioning of the system or lighting only requires alterations to the programming and needs no hardware changes. When the lighting system zones need to be enlarged, new components can be added anywhere in the DALI system, no wiring configuration rules apply on the DALI line in this aspect.

Wiring restrictions do apply to the electrical and the communications.

- The electrical wiring should not be bundled,
- The electrical and communication wiring cannot be located in the same grouping
- The wiring from the ballast to the controller cannot exceed 3m.

All of these wiring restrictions will cause programming, performance and communication issues for the ballasts and system. All wiring and communication drawings should be confirmed by expert technicians and electricians, experienced in DALI installations.

DALI and building automation communication buses

- DALI has a limited system size of 64 addresses.
- There should be a maximum of 20 addresses per loop.
- DALI is meant only for communication in lighting systems. BMS includes other functionality as well (HVAC, fire alarm systems and security.)
- A BAS system commonly has unlimited expansion possibilities, which DALI does not have, to date.

DALI is not competing with BAS systems; it is only complementing them through an interface. The level feedback available is more detailed than other existing lighting control systems and can provide valuable information about the ballast and lamp condition not found in other system. Maintenance can be scheduled in advance of component failures, keeping clients happy.

Electrical Guidelines

Voltages and currents

In the DALI standard all values are specified at the control pins of the ballast. For the full system the situation is slightly different. In general the communication buses voltage in a DALI system is normally 16 V (between 22.4 and 9.5 volts) when there is no communication (idle state). This voltage is supplied from an internal DALI power supply. The digital signal becomes low when the voltage level in the DALI system becomes zero.

Supplying the system

In a DALI system the maximum system current over the communication busses is limited to 250mA, which is supplied from local power supplies. This is to keep the energy consumption low and to ensure digital signal integrity throughout the system. The smallest possible system, one light fitting and a controller consumes a line current of maximum 2 mA for the digital dimmable ballast and the current required by the control equipment. Thus the power consumed is small. Since in practice the impedance of different DALI units are not identical, the selection of the correct system power supply not necessarily straight forward. Good practice is to allow sufficient margins for the supply current. This will guarantee reliable system functionality under different conditions and also allow the flexibility for possible system expansion at a later date. On the other hand, selecting an oversized power supply may cause extra distortion of the control signals. Power supplies, which have so called dynamic current limitation, will be suitable for use in almost every size of system.

Requirements for DALI power supplies.

The DALI power supply must limit the supply current to maximum 250 mA. In practical installations it is good to limit to a lower level, in order to maintain the flexibility of changing the layout and increasing the system at later stages. If the limit is exceeded instability and starting problems may appear in the system. Since the DALI signal varies between 0V and 16V the polarity is important to maintain also with power supply. There is no limitation to having several power supplies on the same DALI control line as long as the current limit is not exceeded and the supply polarity is taken into account.

3.1.3 BACNet Protocol

Building Automation and Control network (BACnet) Protocol is recognized by the International Organization for Standardization as ISO 16484-5. As a standard it sets minimum requirements for manufacturers to meet to receive the standard’s body seal of recognition. It is important to recognize the role BACnet plays in the automation process. As a protocol it is a transporter of data which individual controllers use to read or command devices used to automate systems in buildings.

Standards mature and grow through new innovations and technologies, therefore when standards are being enforced there is always a need to advance toward perfection, thus new versions are introduced regularly. This may happen as often as yearly but most likely to be 3 to 4 years. BACnet since its first release in 1995 has had two revisions and will soon have a third release (2009 most likely).

BACnet is not a panacea for success. It is a tool which, if used as intended, will help keep your project on track The owner must declare his clear agenda for the project team to follow, which includes Open System; for competitive bidding of current and future work, and owner independence from vendor sole sourcing for the short and long term for the facility. BACnet will be a friend for these owners.

Interoperability between Building Automation System (BAS) Vendor Products

BACnet is an **enabler** for different manufacturer's products to interoperate. This is true so long as certain features and services are carefully planned for and adhered to during installation of new equipment. In compliance with BACnet International testing body, each manufacturer must provide a BACnet Protocol Implementation Conformance Statement (PICS) for each of their products. Each device[1] has its own PICS as each device will only include the services and objects that it needs to perform its functions for local (its immediate environment) control.

Caution: Using products bearing the BACnet Test Laboratories (BTL) logo does **not** guarantee full interoperability between manufacturer's products rather it ensures that a minimum set of services can interoperate. This is where the BACnet PICS comes into action where the team must verify that each product that is part of the interaction supports the same (complementary) set of services as the products with which interoperation is required.

The subject of revisions (update to standards) is **key** to the successful expansion of any existing BAS site. This is true even for the extension of systems provided by the same manufacturer and installer. As mentioned above when new revisions of protocol definition are released they are seldom fully backward compatible with previous versions. This is an unavoidable outcome of advancing a standard. Overlooking this important step will result in some services not functioning as expected.

Expanding Systems and Functionality:

It is recommended that a team approach be deployed for this highly involved undertaking. The team planning the expansion must have a team member who has thorough knowledge of the detailed operational sequences of all of the equipment they about to automate. This person should have a thorough knowledge of the BACnet requirements for BAS systems as well as a comprehensive knowledge of the interoperability of all sensors, wiring requirements and addressable protocols. Typical

[1] Devices are as listed in Appendix M - BIBB's table - of the BACnet Standard and are: Operator Workstation B-OWS; Building Controller B – BC; Advanced Application System controller B- ASSC; Application Specific Controller B – ASC; Smart Actuator B – SA; Smart Sensor B – SS.

expansions may include Fire Alarm functionality as well as security and other building related functions.

The team must also be aware that only a few specialist consultants have the overall knowledge to complete a comprehensive specification involving integration and the specialty application experience to meet your sites unique and specific needs. It is therefore recommended to take a team approach with the owner/manager playing a leading role. The end result is that the owner is fully aware of their system long after the contractors are gone. The project team must be knowledgeable about the BACnet BIBB's to ensure the right group of services are included in the requirements definition and during proposal/tender evaluation the BACnet PICS must determine the successful contractor as opposed to lowest cost. This can be a lengthy process but must be followed to ensure full functionality is achieved especially where interfacing with an existing installation. Also remember to check BACnet and DALI versions support on all equipment. If differences exist some of the existing installation may require upgrading which might not have been budgeted for at the project outset.

Remember, experience and planning will make your project a pleasant one instead of one that you want to walk away from. In addition only the project site team will be fully aware of existing habits and customs that the new installation will have to accommodate to be truly successful. A contractor or consultant will not be able to foresee or predict what might occur six months after the project is completed.

3.1.4 Commissioning

As with any installation, commissioning is extremely important to ensure proper functionality and operation of the system and components. Before commissioning begins, the facilities manager or project manager should ensure that the commissioning authorities have a complete set of plans, wiring diagrams, program addressing sequence, proper computer or server space availability and full set of system specifications. It is important for the facility manager to sit down with the contractor to determine the addressing, identification, sequencing, scheduling and programming requirements for each area. For example, to optimize daylight harvesting it likely will be important to provide each workstation with their own specific % of daylight and electric light integration, depending upon location and angle to windows. Workstations right next to windows may get 50% while others, within 20 feet but angles to windows may be programmed for 20%.

It is also important that all occupancy sensors be correctly calibrated. Twenty minutes delay is the norm to ensure that they do not turn off lights or reduce air flow while the person is in their workstation. The newer DALI systems have an intelligence built into them to learn people's movement in and out of workstations over time and adjust the delay off time accordingly.
Ballasts and lamps also need to be commissioned including implementation and functionality testing through the control system. Each ballast control and address should be checked before the system is turned over to the facilities staff. The ballasts and lamps should be seasoned at 100% full output for approximately 100 hours, or over a week-end, to maintain lumen output and lamp and ballast life optimization.

All trending and data collection programming should be verified for reliability of data before the system is accepted.

3.1.5 Churn

Churn is defined as the relocation of employees. It can be a briefcase move; only a few personal items, a box move; or the entire content of a workstation is boxed up and moved to a new location. Both types of churn mean that a new person is being relocated to a new workstation or office. It can also mean that the furniture and office layout may be redesigned. This is where the flexibility of personal environmental control systems can benefit both O&M costs.

The usage of a flexible duct system and air nozzles of the PEC HVAC, means it is easy to relocate the duct and air jet to a new location and reset the programming for the individual's control. The cost is minimal as it does not take technical professionals to do this, nor does it mean turning the location into a construction site.

The same is true of the workstation specific design and the PEC system. The newer luminarie systems and controllers are installed in the ceiling with "plug and play" functionality.

This flexibility ensures that each person has control over their environmental systems and, for a minimal cost, guarantees that the systems will maintain their high level of energy efficiency.

3.1.6 Maintenance

The maintenance of a PEC system is a little more labour intensive than the standard lighting and HVAC passive large zone systems. This means weekly visual inspections of how all of the components are functioning, ensuring the system is maintaining the scheduling and does the energy and system component status data appear to be reliable. This can be spot checked periodically at the Operator WorkStations (OWS) components. For example, is the ballast providing the energy output that is being reported?

The systems that report the status of ballasts, lamps etc., will assist in determining any long term maintenance schedule.

4. Technologies

4.1 Dimming ballasts

Ballasts use a variety of starting methods, however the typical one for dimming ballasts is Rapid Start. This type of ballast uses electrode heated voltage at start and during the operation of the system. Rapid start ballasts utilize a brief delay, but without flicker. This is due to the ballast being provided voltage at approximately 3.5 volts to the electrodes of alternating current. The electrodes are heated up to 1000 degrees C and then the ballast utilizes volt alternating current at 200 to 300 to strike the arc. A newer form of Rapid Start ballast is the Program Start that preheats the electrodes before applying voltage.

Dimming of electronic ballasts is defined as percentage of maximum light output and measured illuminance. The dimming range of a ballast varies with manufacturers but for a PEC system a ballast that has a 0-10 range is recommended.

Ballast life for electronic ballasts is approximately 10 to 20 years. This depends upon the operating state of the system; housing temperature and operating voltage. Temperatures below 40 ^{o}C or above 80 ^{o}C or high peak voltage, typically over 120v, can damage the ballast and reduce the power output to the lamp and life of the ballast.

Dimming ballasts should be let run at 100% for 100 hours to allow lamps time to stabilize before the PEC sensors and control takes over.

4.2 Sensors

Workplace sensors have typically, only been identified as being part of the lighting system. With a PEC system the occupancy sensor can be linked (in software) to the HVAC, air jet, to provide additional energy savings to the building.

Sensors fall into three basic categories, exterior, photocell or daylight harvesting and occupancy or motion sensors. In this guide we will only discuss occupancy and daylighting.

In general daylight and occupancy sensors can be integrated into any BACNet or DALI control strategy. It should be determined what the project objectives are, in regard to energy savings and occupant satisfaction, before either, both or an integrated version of the two controls is chosen.

4.2.1 Occupancy Sensors

Occupancy sensors, by definition, used to turn lights on and off; based upon a determined time detection of motion within a space.

These sensors can be also be used in conjunction with dimming controls to keep the lights from turning completely off when a space is unoccupied or returning to a predetermined light level, when an individual enters the space. This control scheme may be appropriate when occupancy sensors control separate zones in a large space, but do very little to contribute to energy savings These sensors can be used to enhance the efficiency of centralized controls by indicating the opportunity of switching off lights in unoccupied areas during normal working hours as well as after hours but they cannot provide the type of energy efficiency that can be realized, when occupancy sensors are installed in each workstation and incorporated into a personal environmental control strategy.

There are three basic types of occupancy sensors:

- Passive infrared
- Ultrasonic
- Dual-technology (hybrid).

Passive infrared (PIR) sensors react to the movement of a heat-emitting body through their field of view. Wall box-type PIR occupancy sensors are best suited for small, enclosed spaces such as private offices, where the sensor replaces the light switch on the wall and no extra wiring is required. They should not be used where walls, partitions, or other objects might block the sensors' ability to detect motion.

Ultrasonic sensors emit an inaudible sound pattern and re-read the reflection. They react to changes in the reflected sound pattern. These sensors detect very minor motion better than most infrared sensors. Therefore, they're good to use in spaces such as restrooms with stalls, which can block the field of view, since the hard surfaces will reflect the sound pattern.

Hybrid sensors are a combination of an occupancy sensor and a photocell sensor. These are used to detect both motion and light and are typically used in a PEC system.

4.2.2 Daylight Controls

Photocell sensors or photo-sensors, are used to automatically adjust the light output of a lighting system based on detected illuminance. The technology behind photosensors is the photocell. A photocell is a light-responding silicon chip that converts incident radiant energy into electrical current.

While some photosensors just turn lights off and on, others can also dim lights. Automatic dimming can help with lumen maintenance. Lumen maintenance involves dimming luminaires when they are new, which minimizes the wasteful effects of over-design. The power supplied to them is gradually increased to compensate for light loss over the life of the lamp.

Nearly all photosensors are used to decrease the electric power demand for lighting. In addition to lowering the electric power demand, dimming the lights also reduces the thermal load on a building's cooling system. Any solar heat gain that occurs in a building during the day must be taken into account for a whole building energy usage analysis. This is why it is recommended to install photosensors within 10 feet of the perimeter of an office environment or in each workstation that has low partitions and is within 15 to 20 feet of a window.

Dual-technology occupancy sensors use both passive infrared and ultrasonic technologies to minimize the risk of false triggering (lights coming on when the space is unoccupied). They also tend to be a little more expensive than the separate sensors. One can also find some sensors integrated into luminaires. Again the specific requirements of the project should be determined when making decisions about the sensors.

For example, if a workstation specific lighting design is being used and it is determined that a full PEC system will be specified for the project, it is recommended that all sensors be directly connected to the automation system so as to gain maximum flexibility from the sensor values through control logic.

Daylight sensors need to be correctly calibrated to the visual task requirements of the office environment. The following are some recommendations;

- Usable daylight, for office reading tasks, only penetrates 15 feet. Do not use daylight sensors outside of the perimeter area.
- Calibrate to the maximum percentage, expected from daylight harvesting and calculate this against the electric lighting to determine the % of expected daylight.
- If integrating to a daylight control system or shading system, ensure that the sun angle has been determined for each season. Have your consultant provide you with this evaluation.
- Ensure that sensor is cleaned regularly. Dust and dirt will alter the reliability of the illuminance readings.

4.3 Personal Control

Icon Control and Manual Control

Traditional systems come with a manual touch pad control that is located on a partition or wall near the occupant. For a PEC system this control provides information regarding the temperature, set point and adjustment of the air flow and dimming of lighting.

Most manual controls are compatible with all control systems but this should be verified by the consultant or contractor.

The icon control is typically a web based user screen that provides a virtual interactive display pad. For the full PEC system this provides dimming and on/off control of the lighting and temperature based air flow adjustment of the ventilation to by 3 or 4 degrees ˚C. This falls within ASHRAE and COSH regulations and ensures that the overall system is not stressed.

4.4 Conventional Ceiling Air Delivery Systems

Traditional ceiling mounted air delivery systems are typified by the square, round, slot or grill diffusers that supply the air delivered at temperatures in the range of 12 ˚C to 16 deg ˚C. Each diffuser type has its own flow characteristics. The square or round diffusers spread the delivered air in a lateral and downward (20 deg) direction which often causes drafts for persons who may be located in the delivery path. These diffuser types do not work well with variable air volume applications due to the changing flow patterns. As the air quantity decreases from maximum, the throw is reduced and a lowest volume may dump (cold air falls with gravity) cold air on the space immediately below the diffuser location. At full volume the air may reach locations as far away as 4 meters. When the maximum and minimum volumes are more than 2 to 1 in ratio the distance will vary greatly, thus requiring great care in the diffuser location to avoid drafts on occupants.

The traditional approach to calculating the air quantity for comfort conditions in an area is based on determining the heat generated in the space,(equipment, lighting and number of occupants) and determining the quantity of air at a the supply temperature which will offset the heat gain in the space. The required air volume is then spread over a number of diffusers selected to deliver that quantity of air. Traditionally, outdoor air to meet the per person air makeup code requirements is delivered as a component of the conditioned supply air. For this reason a minimum volume is set for each zone so that the outdoor air is always delivered to each zone.

The number of users covered by the above approach often reaches as high as twenty, with only one sensor and one damper regulating the needs for the entire group. If conditions in the space (heat loads from equipment and body heat) for all twenty users are equal to the conditions in the immediate 25 cm from the room sensor with no outside disturbances then all users should be comfortable. This however is neither practical nor achievable in a real situation. ASHRAE Guidelines and LEED recommend that the ratio of users to thermostats be 1 to 1 to accommodate for individual preferences and personalities as well as to overcome variations in equipment loads and influences from adjacent workspaces. The industry guidelines have recently been adjusted to accommodate these recent office requirements.

Operational complaints (too hot, too cold, stale air, drafts) are directly caused by one of the above issues.

When a large number of users are grouped into a single zone, the facility operators have little or no opportunity to make adjustments to accommodate specific user situations. This is not beneficial to user, owner or designers reputations. By bringing the user to control ratio to 1 to 1 the situation becomes self correcting and everyone benefits in the longer term. The type of diffuser discussed so far does not lend itself easily to the 1 to 1 ratio. Size and air patterns are the biggest limitations for this application.

4.5 Air Nozzles

The air nozzle or air-jet provides some unique opportunities which are compatible with the user to thermostat ratio mentioned in previous section. These devices have been on the market for several years from several manufacturers. The use of these devices has been perceived by many designers as for special applications only. ASHRAE Handbook identifies air nozzles and the system design requirements when using these devices. Most notably is the requirement for higher supply air temperatures (17 to 20 ˚C) which to traditional design thinking is not suitable (no in-space cooling capacity). This is a total misunderstanding of the application for the air nozzle. The fan horsepower necessary to supply air nozzles verses other ceiling mounted diffusers is considerably less. The required pressure to reach full flow is in the order of 0.003 H^2O where as slot, grill and square or round require a minimum of .1 "H^2O to achieve the diffusion pattern indicated from the manufacturer.

Contrary to most conventional diffusers the nozzles projects an air jet (air released at a higher velocity which maintains its shape and velocity many diameters from its release point). In so doing the air does not disperse but in fact follows the jet effect until the jet either is lost due to distance and or encounters an object which breaks it up. For this reason a ceiling mounted air nozzle will project air to the space floor normally before it breaks up and then due to the air temperature (cooler than space) it disperses along the floor at a very low velocity. With cooler air at the floor it then replaces air which has been heated by equipment or bodies (following the laws of physics- cool air displaces warm air). Systems using this concept draw warm air up through ceiling slots and return this warmer air back to the air handler where cooling coil capacity is designed to handle the higher return temperatures and the elevated supply temperatures. When installed to operate as described herein, the quantity of air delivered is governed by the warmer air being drawn away. Without exception this quantity will be less than any of the traditional systems.

It is essential for the designer to be aware that within a space there should only be one type of diffuser deployed. Air nozzles are dependent on maintaining the jet effect to function correctly. If other types are introduced in the same space there will be interaction between the air streams and will negate the benefits of both diffusers in the processes. Also of importance is the placement of the air nozzles with respect to the occupants of the space. Placement must always be just behind and to one side of where the user normally sits. Air nozzles with eyeball like swivel functionality permit fine tuning of the air stream after the system and furniture are in place. Air nozzles are ideally mounted on plates which fit into ceiling Tbar grid and a length of flexible round duct permitting them to be relocated easily in any direction up to 2 meters in any direction or at minimum 3 directions from the initial location.

It is important to note that the space the temperature will be elevated when compared with traditional systems … in the vertical plane will be graduated, above normal head height (6 ft to ceiling – don't care zone).

Also note that where indirect lighting (lighting mounted below ceiling) is part of space design, the heat from lighting does not become part of the space cooling load, it is removed directly to the return air path. This does not reduce the AHU coil load but does lower the cooling requirement in the space. The situation would be the same as for ceiling mounted direct lighting fixtures where the heat from lighting goes into the return air stream and is calculated for the cooling coil only. The warmer area (temperature approaching 30 + deg C) is a contributor to higher performance of the lighting components. The improved performance can be as much as 10% over fixtures in a 25 deg C environment.

5. Building Control Standards

5.1 BACNet Protocol

The BACnet **Protocol** Standard 135-1995 (2) was developed by the American Society of Heating, Refrigeration and Air-conditioning Engineers, Inc. (ASHRAE) to promote a common methodology to allow devices from different vendors to communicate with each other. BACnet compatible devices are available from a variety of controls' vendors and equipment suppliers today.

LonWork's LonTalk is a subset of the BACnet standard. LonWorks is often implemented in either a standalone fashion for smaller systems or as the preferred communications method for unitary controllers as a subset of a BACnet installation.

By implementing BACnet, systems made by different companies can communicate with each other. This technology provides the building owner with more choices when it comes to choosing and integrating whole building systems, and even individual building automation components when new automation systems are to be installed or added to a building or campus-wide system.

There are a number of issues that must be considered when specifying a BACnet-based system. These issues focus on selecting BACnet options, which include system architectures. A very important choice in the selection of system architecture is whether or not to allow a gateway to a non-BACnet-based system, or system components, and how to specify this BACnet gateway. The basics of any control system also must not be forgotten; that is, the sequence of operations of the equipment, in addition to the look and feel of the control system.

Specifying a BACnet system cannot by done by simply stating "System shall use BACnet communication protocols." This is a very ambiguous statement that can result in a system that has a completely unexpected architecture. It is very important to give details regarding architecture and system expectations when specifying a BACnet-based system.

BACnet defines each physical point, or software value, in a system as an object. The most commonly used objects are analog input, analog output, analog value, binary input, binary output, and binary value objects. All objects have properties associated with them including, present value, description, status, units, and so on.[iv] Each object has required and optional properties. These are detailed in Appendix C of the BACnet standard for every object type.

The specification, or drawing set, should list each physical connection that will be made to the system, just like the point list in specifications today. Ideally, this list would also include any software parameters associated with each connection point such as, alarms, alarm limits, setpoints, etc. Each of the items listed is treated as an object, with its associated properties within the BACnet system. Again, all required properties for a given object type must be supported by the BACnet device.

The BACnet protocol defines a number of services that are used to communicate between building devices. The protocol services include Who-Is, I-Am, Who-Has, I-Have, which are used for Device and Object discovery. Services such as Read-Property and Write-Property are used for data sharing.

The BACnet protocol also defines a number of Objects that are acted upon by the services. The objects include Analog Input, Analog Output, Analog Value, Binary Input, Binary Output, Binary Value, Multi-State Input, Multi-State Output, Calendar, Event-Enrollment, File, Notification-Class, Group, Loop, Program, Schedule, Command, and Device.
The BACnet protocol defines a number of data link / physical layers, including ARCNET, Ethernet, BACnet/IP, Point-To-Point over RS-232, Master-Slave/Token-Passing over RS-485, and LonTalk.

6. Glossary of Terms

PEC	Personal Environmental Controls – The ability of the individual to control the ambient and ventilation from a touch control pad or icon.
Personal Control	An individual's ability to control some aspect of their workplace environment. Typically applied to control over lighting or ventilation
Controls	Components of a lighting or HVAC system that provide automated control over the functioning of the systems
VAV	A variable air volume device, used in HVAC systems to control the flow of air.
Ethernet	A frame-based computer networking technologies for local area networks (LANs). The name comes from the physical concept of the ether. It defines a number of wiring and signaling standards for the physical layer, through means of network access at the Media Access Control (MAC)/Data Link Layer, and a common addressing format.
Daylight Harvesting	Connects to the electric lighting system and uses continuous dimming ballast that are calibrated and automatically controlled by a photo-sensor,

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