

Figure 1 (left): Ventilation mode at the Richard J. Klarchek Information Commons in Chicago. Figure 2 (right): Hybrid mode.

BACnet® for Green Library

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The Richard J. Klarchek Information Commons integrates state-of-the-art mechanical systems with striking architectural features to create a visually stunning, high performance green building. To ensure the various systems are responding appropriately based on changing building and environmental conditions, BACnet was chosen as the controls protocol.

Information Commons is a four-story 70,000 ft² (6503 m²), bookless digital library constructed on Loyola University's Chicago Lakeshore campus. The building was constructed on the shore

of Lake Michigan surrounded by five other academic buildings in a horseshoe configuration. A major design intent imposed by the University was to make the building as transparent as possible,

providing views through the building to the lake. The building consists of large, open areas with glass façades on each floor bracketed by concrete "bookends" that contain classrooms, meeting rooms, and offices. The partial fourth floor features a large open meeting space with a terrace to the east and a green roof to the west. The ground floor features a café

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and connecting link to the existing Cudahy Library. The main building access is through a “winter garden” entry space on the west side.

To maximize views of the lake, the primary axis of the building is orientated nearly north-south, with large glass exposures on the east and west sides. The University also wanted the building to be energy efficient. With the large east-west glass exposures this was, indeed, a challenge. To address these challenges, many innovative technologies were used. The building has been submitted to the U.S. Green Building Council (US-GBC) for a Leadership in Energy and Environmental Design® (LEED) Silver rating.

The intent of the design was to optimize the energy efficiency of the building while maintaining comfort and indoor air quality for the occupants. To accomplish these goals, the following strategies were incorporated into the design.

Minimize Solar Heat Gain During Cooling Months

The solar heat gain during cooling season was minimized using an automated motorized shading system for the open areas, as well as a ventilated double façade on the west side. Motorized horizontal venetian blinds on the west side are located within the ventilated double façade space, between the inner and outer façade and external to the conditioned space. These blinds can be controlled by automatically rotating the angle of the slats, as well as by raising the blinds.

The celestial calculation of the sun position determines when the sun will impose a load on the west façade and an outdoor light sensor triggers the deployment of the blinds. Once the blinds are deployed, the calculated angle of the sun determines the angle of the slats to avoid any direct beam radiation into the space while maximizing diffuse light for daylight harvesting. There are cavity dampers that open during this mode to allow outside air into the bottom of the interstitial space with awning windows at the top to allow the stack effect heat to escape by natural convection. The draw at the top of the glass stack is further enhanced by the local low pressure created by the prevailing wind (computational fluid dynamic modeling showed that these local low pressures occurred regardless of wind direction).

On the single façade on the east side, there are automatically controlled internal roll up blinds to minimize solar heat gain. The height of the east side shades is controlled to allow direct sunlight to penetrate approximately 4 ft (1.2 m) into the space.

Radiant Ceiling

The coffered precast concrete ceiling has cross-linked polyethylene (PEX) tubing set just above the surface. During the summer months, the ceiling is maintained at an approximate average temperature of 63°F (17°C) or a minimum of 3°F (1.7°C) above the indoor dew point. We predicted the chilled ceiling would provide 4 W/ft² (43 W/m²) of sensible cooling. It was predicted that we could maintain indoor temperatures approximately 2°F (1.1°C) higher¹ than standard due to the radiant effect. Per *2008 ASHRAE Handbook—HVAC Systems*

and *Equipment*, page 6.2, equation 5, the Stefan-Boltzmann governing equation is as follows for radiant chilled ceilings:

$$Q_r = 0.15 \times 10^{-8} \left[(t_p)^4 - (\text{AUST})^4 \right] \quad (1)$$

Where

- Q_r = radiant cooling, Btu/h · ft²
- t_p = mean panel surface temperature, °R
- AUST = area weighted average temperature of the non-radiant panel surfaces of the room, °R

In addition to the radiant energy exchange, there is also a convective component. Per the Handbook, this component can be approximated with the following equation:

$$Q_c = 0.31 \left[t_p - t_a \right]^{0.31} (t_p - t_a) \quad (2)$$

Where

- Q_c = natural convection from a cooled ceiling, Btu/h · ft²
- t_a = AUST for ceiling cooled spaces with large proportions of exposed fenestration, °R

In addition to the energy savings due to higher allowable space temperatures, energy is also saved as a result of the marked decrease in energy transport. Hydronic transport energy is significantly lower than that of an equivalent Btu of sensible energy with air.

The radiant ceiling is cooled using return water from the central chiller plant (typically 56°F to 58°F [13°C to 14°C]), which is injected into the ceiling loop and returned 5°F to 7°F (2.8°C to 3.9°C) warmer. By using return water instead of primary chilled water from the plant, the overall ΔT of the plant is increased, thus improving plant efficiency.

In the heating mode, the ceiling provides radiant heat to the space with supplemental convection fin tube on the east side only. It was also predicted that lower winter indoor temperatures could be maintained due to the warm radiant effect, reducing heating energy.

Natural Ventilation

Based on the energy model, we are predicting approximately 52 days per year during which the outdoor conditions will allow the system to operate in the natural ventilation mode. In this mode the motorized windows on the east (lake side), which open directly to the outdoors, and the motorized windows on the west side, which open to the interstitial space, activate allowing natural cross ventilation across the space. With the awning windows open at the top of the glass stack, there is enough draw to move a considerable volume of air through the space (up to 5 cfm/ft² [25.4 L/(s · m²)). In this mode the fans shut down and all mechanical cooling is shut off. This mode of operation becomes an extremely effective air-side economizer allowing operation up to 72°F (22°C) outdoor temperatures. The building design also incorporated a large ceiling mass that would store the night harvested “coolness” to further extend the natural ventilation bandwidth and further reduce energy use.

Hybrid Mode

To make further use of natural ventilation, the hybrid mode of natural ventilation is set to occur at higher outdoor air temperatures. In this mode windows are open and all fans are off as previously described, and the ceiling is chilled, providing radiant cooling. This mode is only allowed when the outdoor dew point is 5°F (2.8°C) below the chilled ceiling temperature. This mode can provide comfortable space temperatures up to 76°F (24°C) outdoor temperatures.

Demand-Controlled Ventilation

The large center areas are supplied ventilation through a ducted underfloor air-distribution system with high-induction swirl diffusers. The VAV boxes are controlled based on CO₂ sensors with a temperature override. The temperature override was required for periods when the chilled ceiling could not meet the sensible cooling load.

Main Air Handlers

The dual path custom designed air handlers needed to incorporate multiple functions depending on the mode of operation. During the heating mode they function as dedicated outside air system (DOAS) with heat recovery. During the cooling mode, they provide a mixing of conditioned return air and conditioned outdoor air. The outdoor air path incorporates a runaround coil loop that enhances the latent heat removal. The return air path was required to supplement the sensible cooling capacity of the ceiling and to further dehumidify the indoor air. The mixture of these two airstreams (airflows are accurately measured with hot wire anemometers) is controlled by the highest CO₂ zone reading.

The final mode of operation that needed to be incorporated was a smoke evacuation mode in which windows and fans are strategically deployed to quickly evacuate the building of smoke in case of fire.

Efficient Lighting/Daylight Harvesting

The design features include reduced lighting power densities of 1.3 W/ft² (14 W/m²) in the open areas and 1.0 W/ft² (11 W/m²) in the seminar/classroom areas. Active daylighting is modeled to maintain 50 footcandles (538 lx) in the classroom areas and 35 footcandles (377 lx) in the open areas. Daylighting control is continuously dimmed. Visible transmittance is varied by mechanically operated blinds and shades in the east and west glazing.

Building Envelope

The design features upgraded insulation in the roof, wall, and glazing. Half of the third floor roof is vegetative. The west curtain wall consists of two skins with a minimum of 36 in (914 mm) interstitial space used for insulation or as ventilation chimney depending on the weather. A three-story winter garden on the west also buffers the interior. The winter garden is maintained at a minimum of 40°F (4°C) with the radiant floor heat in the winter and is ventilated in the summer.

Controlling Indoor Dew Point

Controlling indoor dew point was important from the standpoint of maintaining the chilled ceiling temperatures without risk of condensation. The indoor dew point was controlled based on the following system:

- The outside ventilation air for the open areas is conditioned through a three-coil runaround system that significantly improves the dehumidification capacity of these systems. The warmer the outside air, the more effective this configuration is related to dehumidification.
- There is a separate return air path on the open area air handlers (AHU-1 through 4) with staged coils that will provide dehumidification of the space. By staging the coils in the return air path, the air that passes through the active coil can be cooled to 55°F (13°C) for maximum moisture removal and mix with the room temperature air through the inactive coil to supply air to the underfloor system in the 63°F (17°C) range.
- The classroom units are conventional VAV systems with cold air supplied at the ceiling. These systems will assist the dehumidification of the adjacent open area space.

Control Sequence

The BAS control system must be robust to integrate all these systems into an intelligent smooth functioning system. A detailed control sequence was written to define the five modes of operation (heating, cooling, natural ventilation, hybrid, and smoke evacuation). Cooling was defined as the default mode with specific parameters defining the transition and time delays to other modes. A complete weather station was incorporated as part of the design to measure light levels, wind, dew point, dry-bulb temperature, and precipitation. For example, if precipitation is sensed, the windows close and the system switches out of natural or hybrid mode. If the fire alarm system sends a smoke evacuation signal to the BAS, the system commands the first floor windows to open, the east side shades to open, the interstitial windows closed, the awning windows open, blinds up, dampers at the air handlers switch position, and the exhaust fans rev up to high speed.

BACnet Integration

Loyola University decided several years ago to use BACnet as its building controls communication protocol. The total quantity of BACnet I/O objects currently exceeds 26,000 physical points. The majority of the BACnet objects are provided by the vendor's BACnet system.

Working in collaboration with the University's IT department, the facilities group created a virtual LAN (VLAN) for the building controls network. The VLAN is deployed across the campus IT network, and enables building controls to communicate using BACnet over Ethernet, reducing the complication of standard IP-based communications. Choosing a VLAN made it easier for the IT group to manage the building controls network traffic. As new controllers are added, the IT group provides a network

drop and the Ethernet enabled controller is connected to it and it then appears on the facility LAN.

A critical design component for large campus networks is to design an addressing scheme early on. The addressing scheme is important because there can be no duplicate device addresses in a BACnet network. Each controller requires a unique device ID. At Loyola University a seven digit number is used, the first digit identifies the campus, the following two digits identify the building, and the last four digits represent the controller. This system works well for the university and ensures that it is easy for them to add new buildings. It also keeps all controllers grouped together in an orderly fashion when they are viewing the system across the network.

During this project the IT group offered to provide the facilities group with access to a virtual server for the server application used to provide access to the facility BMS system using a Web-browser interface and the server application that is used to gather and store long-term trend data for facility operations. A virtual server is a Web server that shares common computer resources with other virtual servers. The virtual component means that it is not a dedicated server. The entire computer is not dedicated to running the single applications server software, multiple server applications can run on a single computer. Although the software applications had never been deployed on a virtual server before, they deployed flawlessly. The server platform was running Windows Server 2003, Enterprise Edition.

A benefit of using BACnet is the ability to extend the campus network with relative ease. Loyola made good use of this ability during this project. Prior to occupancy, a decision was made to integrate the building controls from the Information Commons building onto the campus WAN. The project was wrapping up during the winter, and it was felt that it was more cost-effective to manage the building through the existing campus facility management team, rather than having it operate in a stand-alone manner. Because the network architecture was well thought out, connection to the existing campus WAN was as simple as plugging a cable into the switch. As soon as that was done, all controllers appeared at the operator workstation, and the facility operators began to monitor and manage the facility like all the rest.

BACnet Facilitates Interoperability

With a specific requirement to reduce and monitor energy consumption, the Information Commons has been outfitted with several submeters. These devices monitor water consumption and measure the supply and return water temperature for the building and for the radiant ceilings. These devices are BACnet and use the BACnet MS/TP protocol. Power meters are used to measure and trend building electrical consumption and demand. This information is used to generate reports on hourly, daily, and monthly kWh use, as well as peak kW demand for each month. These data points are trended and displayed on graphic screens, and the reports available for each sub-meter by day, month or

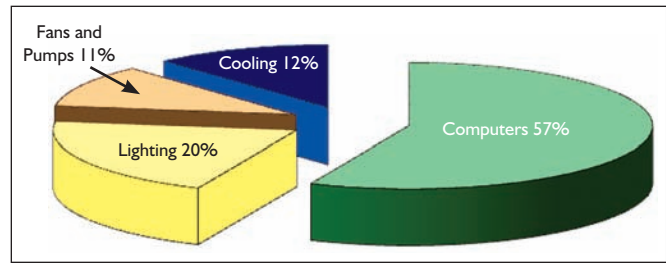


Figure 3: Building power usage.

year. The power meters use Modbus protocol, and therefore a DSM-RTR was required to convert the Modbus protocol to BACnet Ethernet.

Integration to the window blinds was also required. The window blinds were sourced from Europe and came with a non-BACnet protocol installed. To control the blinds, a gateway was supplied by the blind manufacturer. This gateway was configured by a representative of the blind manufacturer.

Window operators were sourced from Italy, and are controlled with relays. Two relays are used to control a group of four windows. One relay is energized to indicate direction of operation, and the second relay energizes the actuator.

A shade control system is connected to the BACnet network via a custom BACnet interface. Through this interface the shades on each floor are adjusted based on the outdoor light level.

The building is equipped with a full weather station, which includes outside temperatures, wind speed direction, precipitation detection, and a photocell. This information is brought onto the BACnet network, and is used to control the relative position of the blinds, windows, and shades, to maintain occupant comfort. If the wind speed is too strong off the lake, the windows are closed. The windows are also closed if there is a snow or rain condition.

The VAV controllers were required to be UL864 rated for smoke control. These controllers were programmed using the specified UL864 programming sequence for integration with the smoke control system. If a smoke detector is activated, then the VAV system will modulate to create a situation in which the smoke for that affected area is evacuated from the space in the most efficient manner possible.

The systems in this building are required to interoperate in a truly intelligent fashion. The robustness of the BACnet protocol and some gateway implementations has enabled this high-tech facility to operate according to the design requirements.

Energy Model

The energy model for the building predicted 52% lower energy consumption than ANSI/ASHRAE/Standard 90.1-2001. The total predicted site energy without plug and computer loads was 50.4 kBtu/ft²/year (572 544 kJ/m²·yr). The total site energy predicted with plug and computer loads was 65 kBtu/ft²/yr (738 400 kJ/m²·yr). The building was modeled for 24/7 occupancy.

Note that the model showed domestic hot water production from natural gas, which was later changed to point of use electric. Also note that although the source of chilled water and hot water is from a central plant, the thermal energy was converted to plant energy using the average measured efficiency of the plants (0.6 kW/ton [0.17 kW/kW] including auxiliaries for cooling and 82% for steam to fuel efficiency).

Actual Energy Data

All the electric and thermal energy is being measured. The thermal (Btu) meters were up and running since July 18 of this year. From July 21 to August 20, the thermal energy was lower than anticipated while the electrical energy was greater than anticipated. After analyzing electric meter data and taking field measurements, the following breakdown of power usage is shown in *Figure 3*.

There are 300 PCs in the building. Although the model assumed that idle computers would go in stand-by mode, it was determined that they remained in the ready mode 24/7 collectively consuming more than 1 W/ft² (11 W/m²). The University is in the process of modifying this. This scenario illustrates the importance of the measurement and verification process.

Observations

The natural ventilation and hybrid modes were the most challenging to commission. However in a two week period in August, the building was either in natural ventilation or hybrid mode 37% of the time. The natural ventilation mode is so effective that the indoor temperature could be maintained within approximately one-half degree of the outdoor temperature.

With the proximity of the building to Lake Michigan, the audible rhythm of the waves in the natural ventilation mode further enhances the overall aesthetics of the building.

The building opened last January and the user's report that this is the most comfortable space on campus.

Conclusion

Part of the beauty of the building includes how it dynamically and intelligently responds to the outside environment. One of the goals of the project was to create the experience inside of being outside on a spectacular day. As engineers, we are more concerned with function than form.

In this building function and form come together in a unique way.

References

1. Mumma, S. "Chilled ceilings in parallel with dedicated outdoor air systems: addressing the concerns of condensation, capacity, and cost." *2002 ASHRAE Transactions* 108(2):220–231.●

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