Loyola University Chicago's digital library operates in natural and hybrid ventilation modes, which take advantage of breezes from Lake Michigan.

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Efficiency by the Book

BY DONALD J. MCLAUCHLAN, P.E., MEMBER ASHRAE; DAVID LAVAN, MEMBER ASHRAE

Loyola University Chicago's Richard J. Klarchek Information Commons Building is a library without books. Instead, its role is to provide technology in a library-like setting that is ideal for study and research. The university aimed to give students an indoor experience similar to being outdoors on a beautiful day by providing views through the building to Lake Michigan. The 70,500 ft^2, four-story digital library's advanced mechanical systems combine with the visually stunning architectural features to create a high performance building.

The primary axis of the building is oriented nearly north-south with large glass exposures on the east and west sides. The exterior envelope includes a double-skin curtain wall on the west side, enclosing a 3 ft wide cavity, and a single-skin curtain wall to the east facing the lake.

Three floors of open and partitioned study areas form "shelves," which are flanked by limestone precast "bookends" that house classrooms. The ground floor includes a café and connecting links to the existing library and chapel.

Sustainable Strategies

Dual Temperature Radiant Ceiling

The main ceiling consists of coffered precast concrete panels with cross-linked polyethylene tubing set just below the surface (*Figure 1*). Due to the contour of the ceiling, care was taken to avoid air traps. The ceiling system is designed to meet 60% of the design sensible cooling load with approximately 4 W/ft^2 of cooling power density at 80% ceiling coverage. A ducted underfloor air system provides ventilation air and supplements the radiant cooling systems on design days.

The building automation system (BAS) maintains the ceiling temperature between 62°F and 67°F as required for cooling, or 3°F higher than the measured indoor dew point to prevent condensation. The indoor dew point is based on the highest of several measured values.

The BAS adjusts the supply water to the slab based on a 12-hour average variance from space setpoint while monitoring actual slab sensors to ensure temperatures are within the described thresholds. It is estimated that indoor temperatures can be maintained approximately 2°F higher[1] than standard due to the radiant effect of the chilled ceiling.

The radiant ceiling is cooled using return water from the central chiller plant (typically 56°F to 58°F), which is injected into the ceiling loop and returned 5°F to 7°F warmer. In the heating mode (*Figure 2*), the ceiling provides radiant heat to the space with supplemental convection finned tube on the east side only.

Natural and Hybrid Ventilation

In natural ventilation mode (*Figure 3*), automatically controlled modulating operable windows on the east façade, as well as on the inner windows on the west double façade are opened. These windows, in conjunction with the motorized awning windows at the top of the double-wall glass stack,

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East and west glass façades preserve campus views of Lake Michigan. Masonry "bookends" on the north and south ends house classrooms.

BUILDING AT A GLANCE

Name The Richard J. Klarchek Information Commons Building

Location Loyola University Chicago Lake Shore Campus

Owner Loyola University Chicago

Principal Use Student/faculty digital library
- **Includes** Classroom/seminar rooms, open area commons with computers, café

Employees/Occupants 965

Gross Square Footage 70,500 ft^2

Total Cost $28 million

Cost Per Square Foot $397

Substantial Completion/Occupancy January 2008

Occupancy 70%

Distinctions/Awards LEED Silver; First Place, 2010 ASHRAE Technology Awards

ENERGY AT A GLANCE

Energy Use Intensity (Site, with plug loads) 84 kBtu/ft^2

Energy Use Intensity (Site, without plug loads) 59.7 kBtu/ft^2
- **Natural Gas** 34.7 kBtu/ft^2
- **Electricity** 25.0 kBtu/ft^2

Annual Source Energy 119.8 kBtu/ft^2

Annual Energy Cost Index (ECI) $0.88/ft^2

Savings vs. Standard 90.1-1999 Design Building 46%

ENERGY STAR Rating 85.6 (based on 2008 data)

Note: Energy values exclude plug loads except where otherwise noted.

KEY SUSTAINABLE FEATURES

Water Conservation Ultra low-flow urinals (one-eighth gallon per flush), dual-flush toilets and low-flow lavatories

Daylighting Active, automatically controlled daylight harvesting

Individual Controls Individual thermostats for classrooms and study rooms in "bookends," as well as occupant operable windows in "bookends;" study rooms in open areas controlled independently

Other Major Sustainable Features Natural ventilation, double façade with interstitial shading, radiant heating and cooling, demand controlled ventilation and energy recovery

BUILDING ENVELOPE

Roof
Type Concrete/insulated and vegetative
Overall R-value 40
Reflectivity 0.4

Walls
Type Insulated precast concrete panels with additional insulation
Overall R-value 13.7
Glazing percentage 48

Basement/Foundation
Slab edge insulation R-value 10
Under slab insulation R-value 10

Windows
U-value
- Double façade 0.23
- Other 0.46

Solar Heat Gain Coefficient (SHGC)
- Double façade 0.49
- East open area 0.35
- Other 0.27

Visual Transmittance
- Double façade 0.64
- East open area 0.63
- Other 0.45

Location
Latitude 42
Longitude -87.656
Orientation West (double) façade 252° off north

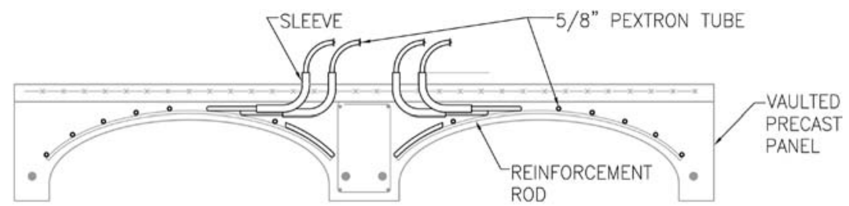

Figure 1 **This section view of the precast coffered concrete ceiling panels shows the polyethylene tubing for the dual temperature radiant ceiling.**

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facilitate effective natural ventilation throughout the open areas.

This effectiveness is achieved with the combination of the negative pressure created by the thermal buoyancy of warm air in the west side interstitial space as well as the effect of the wind blowing across the top of the glass stack. The interstitial space is naturally ventilated with intake air entering through cavity dampers at the bottom and exhausting through awning windows located at the top of the four-story glass stack.

This system draws air (up to 5 cfm/ft^2) from the eastern lakeside windows, across the open areas and through the inner west side windows. The natural ventilation mode is so effective that the indoor temperature can be maintained within approximately 0.5°F of the outdoor temperature. The rhythm of the lake waves is audible in the natural ventilation mode, further enhancing the aesthetics of the building.

The hybrid mode (*Figure 4*) allows natural ventilation to occur at higher outdoor air temperatures. In this mode the windows are open, all fans are off, and the ceiling is chilled to provide radiant cooling. This mode is used only when the outdoor dew point is 5°F below the chilled ceiling temperature. This mode can provide comfortable space temperatures up to a maximum outdoor temperature of 76°F. During a two-week period in August 2008, the building was either in natural ventilation or hybrid mode 37% of the time.

Automated Shading

Solar heat gain during cooling season is minimized by using an automated motorized shading system. The calculated 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. The sun's location also determines the angle of the slats to avoid any direct beam radiation into the space while maximizing diffuse light for daylight harvesting.

On the east side single façade, automatically controlled internal roll-up blinds minimize solar heat gain. The position or height of the east side shades allows approximately 4 ft of sunlight into the space.

HVAC Systems

A ducted underfloor air-distribution system with high induction swirl diffusers supplies ventilation for the large open computer areas. The variable air volume (VAV) boxes are controlled based on CO_2 sensors (with temperature override) to maintain CO_2 levels below 1,000 ppm. There is a temperature override for each VAV box for periods when the chilled ceiling cannot meet the sensible load. The bookends' ventilation

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Above **Precast concrete panels with cross-linked polyethylene tubing compose the Information Commons' dual temperature radiant ceilings.**

Left **The radiant effect of the coffered precast concrete ceiling allows higher space temperatures in cooling mode and lower space temperatures in heating mode.**

FIGURE 2 **HEATING MODE**

When the building is in heating mode (designed to operate 202 days per year), the ceiling provides radiant heat to the space with supplemental convection finned tube on the east side only.

FIGURE 3 **NATURAL MODE**

In natural ventilation mode (designed to operate 52 days per year), automatically controlled operable windows on the east façade and the inner windows on the west double façade are opened.

FIGURE 4 **HYBRID MODE**

In the hybrid mode (designed to operate 62 days per year), windows are open, all fans are off, and the ceiling is chilled to provide radiant cooling. This mode allows natural ventilation to occur at higher outdoor air temperatures.

FIGURE 5 **COOLING MODE**

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In cooling mode (designed to operate 50 days per year), a ducted underfloor air system provides ventilation air and supplements the radiant ceiling cooling system on design days.

system uses a conventional VAV system with colder than normal supply for improved dehumidification. There are linear slot diffusers in the ceiling and a ceiling return for the bookends.

Dual-path custom-designed air handlers incorporate multiple functions depending on the building operation mode. During the heating mode, they function as a dedicated outdoor air system (DOAS) with heat recovery. During the cooling mode (*Figure 5*), the air handlers provide a mixing of conditioned return air and conditioned outdoor air.

The air handler outdoor air paths each incorporate a runaround coil loop that enhances the latent heat (moisture) removal in cooling. A separate return air path further dehumidifies the space.

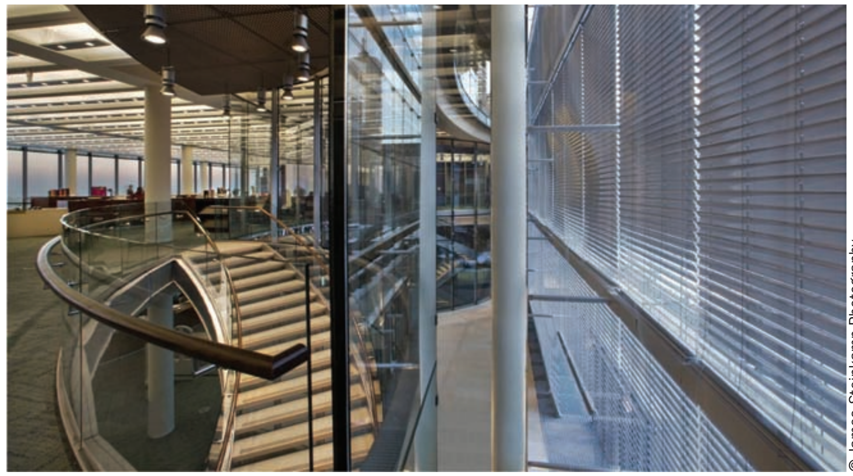
The return air path uses a stacked coil arrangement, allowing part of the air to be cooled low enough to effectively dehumidify the air. The mixture of the outside air and return air in cooling is controlled by the highest CO_2 zone reading. In cooling, the west interstitial windows provide exhaust relief. In case of fire, windows and fans are deployed to exhaust smoke.

Daylight Harvesting

The building design includes reduced lighting power densities of 1.3 W/ft^2 in the open areas and 1 W/ft^2 in the classroom areas. Active daylighting is controlled to maintain 50 footcandles (fc) in the classroom areas and 35 fc in the open areas. Daylighting controls respond to changing light conditions in the space.

Control Sequence

A detailed BAS control sequence was written to define the five modes of operation (heating, cooling,



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Left **A double-skin curtain wall on the west side encloses a 3 ft wide cavity. The interstitial space is naturally ventilated with intake air entering through cavity dampers at the bottom and exhausting through awning windows located at the top of the four-story glass stack. Automated blinds reduce heat gain.**

TABLE 1 ELECTRICITY USE

Month	kWh Actual	ASHRAE 90.1-1999 (kWh)	Electricity Consumption (kBtu)	Cooling Degree Days	Cooling Degree Days Average (2002-07)	Cost
Aug 08	85,213	156,400	290,833	246	260	$6,098
Sep 08	88,196	127,200	301,013	90	114	$6,311
Oct 08	83,873	105,300	286,259	10	21	$6,002
Nov 08	80,958	94,500	276,310	0	0	$5,793
Dec 08	85,263	97,100	291,003	0	0	$6,101
Jan 09	83,377	97,100	284,566	0	0	$5,966
Feb 09	86,198	87,800	294,194	0	0	$6,168
Mar 09	92,452	97,200	315,539	0	1	$6,616
Apr 09	96,753	95,200	330,219	2	15	$6,924
May 09	68,350	118,100	233,277	18	45	$4,891
Jun 09	74,031	142,600	252,667	157	179	$5,298
Jul 09	80,742	161,200	275,571	150	300	$5,778
Total	**1,005,406**	**1,379,700**	**3,431,450**	**673**	**935**	**$71,946**

Note: kWh actual includes metered chilled water converted to kWh based on an average chilled water central plant efficiency as well as metered electrical data.

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Daylighting and reduced lighting power densities of 1.3 W/ft^2 in the open areas and 1 W/ft^2 in the classroom areas contribute to the energy efficiency of the building.

natural ventilation, hybrid, and smoke evacuation). A weather station measures light levels, wind, dew point, dry-bulb temperature and precipitation.

Environmental Impact

The installation of low-flow fixtures reduces waste discharge. These low-flow fixtures include 1/8 gallon per flush urinals and 1/2 gpm lavatories used in all of the bathrooms. Dual-flush toilets also are installed throughout the building.

The fourth floor meeting area is flanked by a green roof area that provides additional insulation, controls temperature, reduces storm water runoff and absorbs much of the additional solar energy. By minimizing the building's energy use, greenhouse gas emissions are reduced as well.

Energy Evaluation

Submeters measure chilled water, dual temperature water and electricity use. *Tables 1* and *2* show one year of energy use. Cooling energy was low because the system was in either natural ventilation or hybrid mode a significant percentage of the time. Heating energy was higher than expected due to some gasket and window actuator issues with the operable windows. This issue has since been resolved.

The plug load, process load and base energy totals were higher than expected. These loads were determined by measuring the unoccupied electric load with all of the fans, pumps and lights off. This was compared with the average energy used on holidays when the building was unoccupied and all systems were also off.

TABLE 2 NATURAL GAS USE

Month	Therms Actual	Therms Actual (Adjusted for Heating Degree Days)	ASHRAE 90.1-1999 (therms)	Natural Gas Consumption (kBtu)	Heating Degree Days	Heating Degree Days Average (2002-07)	Cost
Aug 08	0	0	152	0	0	7	$0
Sep 08	0	0	383	0	50	72	$0
Oct 08	1	1	1,638	88	387	381	$1
Nov 08	1,506	1,387	4,508	150,627	766	705	$1,506
Dec 08	6,277	5,301	8,207	627,701	1,302	1,100	$6,277
Jan 09	7,253	5,604	9,236	725,289	1,516	1,171	$7,253
Feb 09	5,448	5,672	7,030	544,762	1,023	1,065	$5,448
Mar 09	4,291	4,556	5,604	429,085	781	829	$4,291
Apr 09	2,219	1,929	2,268	221,899	526	457	$2,219
May 09	0	0	796	0	171	234	$0
Jun 09	0	0	213	0	71	34	$0
Jul 09	0	0	115	0	9	1	$0
Total	**26,994**	**24,450**	**40,150**	**2,699,449**	**6,602**	**6,056**	**$26,994**

Note: Natural gas is used only for heating and is based on metered heating hot water use and an average central boiler plant efficiency.

Right When not in natural ventilation or hybrid mode, the open areas use a dedicated outdoor air system with zone level CO_2 sensors.

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These measurements were used to calculate the energy use excluding plug loads, process loads and base energy to compare with the design energy model. The plug and process loads are actually higher than this because computers (including 300 personal computers for student use) and copy machines typically use more energy than was measured in the unoccupied mode. *Table 3* is a breakdown of the base energy usage.

Excluding plug and process loads, this 24/7 building was predicted to perform 52.8% better than an ASHRAE Standard 90.1-1999 base building. The building actually performed 46% better. The total energy use with plug loads was 84 $kBtu/ft^2 \cdot yr$ and without plug loads was 60 $kBtu/ft^2 \cdot yr$ (*Table 4*).

Several design strategies maximize the building's energy efficiency. Higher allowable space temperatures in cooling and lower allowable space temperatures in heating due to the radiant effect combined with the decrease in transport energy result in significant energy savings. In addition, by using return water for the radiant ceiling as opposed to primary chilled water from the plant, the overall ΔT of the plant is increased, improving plant efficiency.

The automated motorized shading system and a ventilated double façade help minimize solar heat gain during the cooling season. The natural ventilation and hybrid modes eliminate fan energy and minimize mechanical cooling. The ventilation modes of operation function as an effective air-side economizer, allowing natural ventilation up to a maximum outdoor temperature of 72°F.

The large ceiling mass also stores the night harvested coolness to further extend the natural ventilation bandwidth and reduce energy use. The dedicated outdoor air system controls VAV boxes based on CO_2 sensors, reducing energy use when spaces are unoccupied. Reduced lighting power densities and dimming as a result of daylight harvesting also limit energy use.

Indoor Air Quality

The building's lakeside location made this project an ideal candidate to take advantage of nature whenever possible to create indoor comfort. According to the energy model, outdoor conditions allow the system to operate in the natural ventilation mode approximately 52 days per year.

When not in natural ventilation or hybrid mode, the open areas use a dedicated outdoor air system, which distributes ventilation air with an option for some recirculation during certain conditions in cooling mode only. The ducted underfloor system uses high induction diffusers and a ceiling return. The bookends have linear slot diffusers in the ceiling with a ceiling return.

Each of these operation modes meets ASHRAE standards for ventilation effectiveness. Furthermore, the air diffusion performance index values for terminal devices are 90% and 80% for the open areas and bookends, respectively.

Comfort

Student and faculty feedback has been positive since the facility opened. The building is often fully occupied and is described as one of the most comfortable places on the university's campus.

TABLE 3 BASE PLUG/PROCESS LOAD SUMMARY

Café (unoccupied)	5.5
Transformers	10
Emergency lighting	7
Plasma TVs, water coolers, copiers, fourth-floor refrigerator and misc. plug loads	8.5
Automatic transfer switch 2 (UPS, smoke evacuation, etc.)	4.9
Computers in unoccupied mode	20.6
Total Base Load	**56.5 kW**
Annual Base Energy Load	495,170 kWh

Note: The base load data are based on panel measurements made during unoccupied times on several school holidays with all systems off. The transformer losses are based on zero load measurements on each transformer. Two waterfall 7.5 hp pumps have been added (operating from 6 a.m. to 10 p.m.) since the base load was measured.

TABLE 4 ACTUAL USE VERSUS DESIGN MODEL

	Actual Use Plug, Process Loads	Actual Use without Plug, Process Loads	Design Model without Plug and Process Loads	ASHRAE 90.1-1999 without Plug and Process Loads
Gas (kBtu)	2,444,967	2,444,967	1,683,500	4,015,100
Electricity (kBtu)	3,431,450	1,741,434	2,000,663	3,785,430
Total (kBtu)	**5,876,416**	**4,186,401**	**3,684,163**	**7,800,530**
$kBtu/ft^2 \cdot yr$*	84	60	53	111

*24/7 occupancy

The Information Commons building team sought to maintain the visual, audible and tactile connection with the outdoors through the natural ventilation, sound transmission, a green roof and building transparency.

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Although the initial construction cost for the Information Commons was higher than conventional, energy efficiency measures allow for lower operating costs and a greater long-term rate of return.

Since the building is a student library setting, a general metabolic rate of 1 to 1.2 was assumed for the majority of building occupants. Clo values of 0.5 and 1 for summer and winter, respectively, were assumed for the college campus setting. Given these parameters, the graphical method of determining acceptable comfort ranges per ASHRAE Standard 55-2004 was used.

Since the building is served by a chilled ceiling, careful indoor humidity control was required as described earlier. Given the high induction swirl diffusers used in the underfloor air system of the open areas and the slot diffusers in the high ceilings of the bookends, the air velocities in the space were assumed to be less than 40 fpm. As such, the operative temperatures of the spaces were calculated as the mean value of air temperature and mean radiant temperature.

In the main open areas, where the ceiling is chilled in cooling and heated in heating modes, the operative temperature with a 77°F indoor air temperature in cooling mode was calculated as 75°F. In heating mode the operative temperature was calculated as 72°F for an air temperature of 70°F.

The temperature of the ceiling of each floor can be individually controlled with separate slab temperature sensors in each ceiling as well as two separate water circuits for the east and west portions of each ceiling. These operative temperature values result in acceptable comfort according to ASHRAE standards. Both the open areas and the bookends have tight zone control.

Maintenance and Operation

Building staff has reported that maintenance and operation of the mechanical building systems is convenient. For example, although the open areas have accessible raised floors, all VAV boxes are installed in the fourth floor mechanical rooms for easier access.

Our engineers have been intimately involved in the building commissioning process (a third party was used) and continue to monitor the building systems and alter them as needed (i.e., plug load energy use).

Evaluating Costs

The mechanical, BAS, testing, adjusting and balancing (TAB), and east side operable window system were bid out separately. Mechanical was $2,185,000, controls (BAS) was $673,000, TAB was $55,000 and the east side operable windows were $96,000. The combined cost is approximately $43/ft^2, which is nearly equivalent to a conventional system.

The cost of the precast concrete radiant system was largely offset with smaller ductwork required for the DOAS. Using the existing campus central plant reduced the capital equipment needed for the project.

Although expensive, the double-ventilated façade was an integral part of the aesthetics of the building; however, the cost was partially offset by a $200,000 state grant. The university has attributed its increased enrollment in part to the positive publicity that the building has received.

The initial construction cost for the Information Commons was higher than conventional, but energy efficiency measures allow for lower operating costs and a greater long-term rate of return. The environmental impact was minimized by maintaining the visual, audible and tactile connection with the outdoors through the natural ventilation, sound transmission, green roof and building transparency. Users report that the building is the most popular space on campus. ●

LESSONS LEARNED

The natural ventilation system was the most challenging to commission. Loyola's project management team spent a long time working through some issues with unreliable window actuators and insect screens on the east façade. The manufacturer ultimately replaced those actuators with a different model and the windows now operate reliably.

The building has performed better than expected in the natural ventilation mode. Typically the system is operating in either natural or hybrid mode when outside air temperatures are between 55°F and 75°F.

Although the HVAC and lighting energy was lower than expected based on our model, the base building electrical load (with all HVAC equipment and lighting turned off) was higher than anticipated (*Table 3*). We measured the primary load of transformers with the secondary shutoff to determine the base inefficiency of the transformers. We were surprised how high it was despite installing the most efficient transformers (80°C temperature rise in lieu of 115°C or 150°C). In future designs we will be more concerned with these losses.

Seasonally, we were surprised by how high the electrical consumption of computers was during the unoccupied mode. We have explored methods of allowing computers to go into a low energy sleep mode when idle and automatically waking them in the evenings for required software updates.

BUILDING TEAM

Building Owner/Representative
Loyola University Chicago

Architect
Solomon Cordwell Buenz

General Contractor
Pepper Construction

Mechanical Engineer
Elara Engineering, Transsolar KlimaEngineering

Electrical Engineer
Elara Engineering

Energy Modeler
Elara Engineering, Transsolar KlimaEngineering

Structural Engineer
Halvorson and Partners

Civil Engineer JJR

Landscape Architect JJR

Lighting Design Charter Sills

LEED Consultant Sieben Energy

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