Integrating structure and HVAC to increase ceiling heights can maximize natural light and help reduce building energy use.

Shining Through

BY WAYNE PLACE, PH.D., AND JIANXIN HU, PH.D.

WHILE MOST PEOPLE understand the structural engineer's role in reducing the environmental footprint of a framing system, fewer understand their potential to also reduce a building's energy use and operating costs. One such opportunity is not just a structural matter. The approach described in this article involves delivery of thermally conditioned air in an underfloor plenum and the removal of stale air through a ceiling plenum and high ceilings to enhance the penetration of natural light to the core of the building.

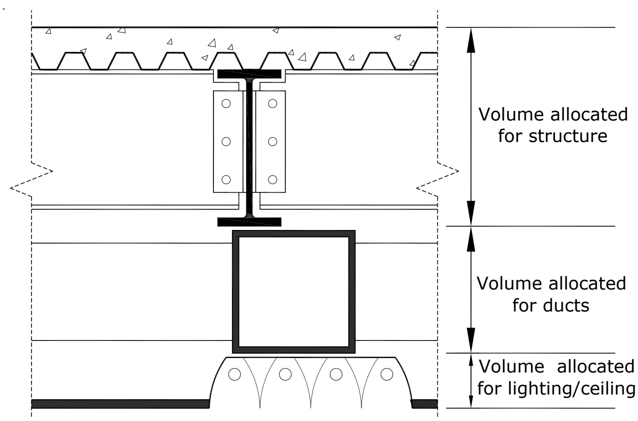


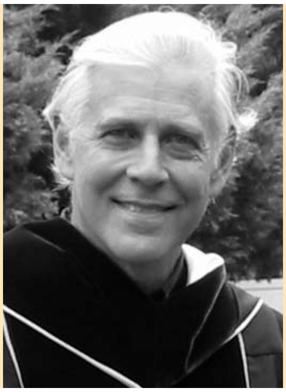
Figure 1: Traditional layering of the systems.

Before Electricity

Before we get into the specifics of such a setup, let's first take a look back at how building lighting has evolved over time. Prior to the advent of electric lighting, the massing and height of most buildings were dictated by the need to get natural light deep into the building. Getting the daylighting aperture as high as possible in the wall is also crucial to getting light incident on the work plane at an angle that provides adequate illumination and light quality for the tasks being performed on the work plane.

Incandescent lighting started to change this relationship almost immediately. Many years later, the advent of fluorescent lighting made it possible to lower ceilings, and buildings gradually became no longer dependent on natural light as a primary source for interior illumination.

The volume that was freed up by lowering the ceiling was typically consumed by dividing it up between the various building subsystems. Under every roof or floor, the structural support system has been given an expansive horizontal volume deep enough to accommodate the deepest spanning member. Beneath that, the HVAC system has been given an expansive horizontal volume deep enough to accommodated the largest duct in the system. Beneath *that*, electric lighting has been given an expansive horizontal volume deep enough to allow electric lighting fixtures to be maneuvered and inserted, often between the T-bars of the hung ceiling. The situation is graphically summarized in the diagram in Figure 1.



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In this design process, vast amounts of hidden building volume are empty and dark at the expense of light, airy spaces that provide occupants with a sense of connection to the outside world. The design process has become more like "volume allocation" rather than coordination or integration of systems. True systems integration has the virtues of providing better architectural spaces for human occupation and reducing lighting electricity consumption. To achieve these goals, design effort and research must be focused on ways of getting the subsystems to share volumes, so that the ceilings can be raised to allow light to penetrate into the building.

Glazing Design and Building Shape and Orientation

Glazing area must also be analyzed and addressed. For façades that receive little or no beam sunlight, a "typical" glazing system consists of a panoramic band of view glazing between about 3 ft and 7 ft above the finished floor, with a panoramic band of daylight glazing extending from the top of the view glazing up to the ceiling. For façades that receive substantial amounts of beam sunlight, the glazing can be protected from unwanted solar gains by placing an exterior overhang above the view glazing, and from glare by placing an interior light shelf just below the daylight glazing. An example of this is shown in Figure 2, where the perimeter wall, shown on the left, is outfitted with an exterior overhang and an interior light shelf. Shown on the right of Figure 2 is a partition wall that is glazed to allow light to pass into the core of the building.

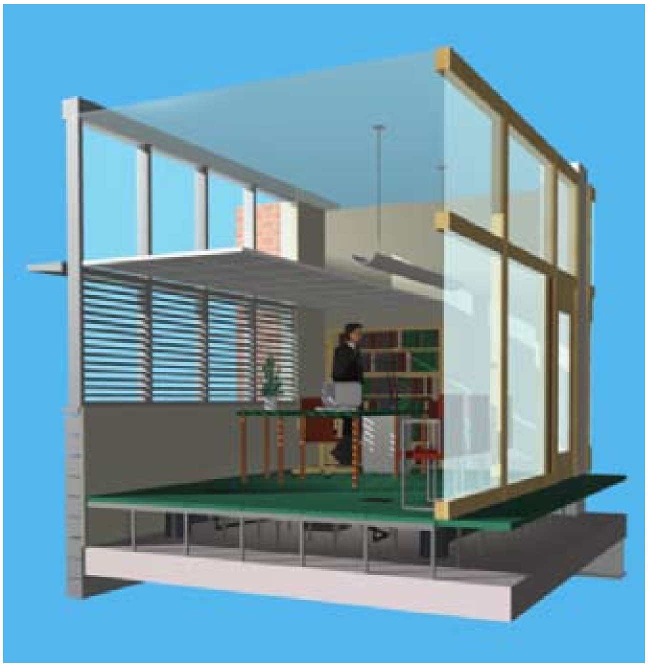

Figure 2: Glazing system with overhang and light shelf (on the left). Rendering courtesy of Williard-Ferm Architects, Raleigh N.C.

It is feasible to design a building with a simple glazing system that admits enough natural light through the exterior facade, during almost all daylight hours, to fully illuminate all the space within 15 ft of the walls. About half of the required light level will be provided between 15 ft and 30 ft from the light-admitting wall. This means that a building that is about 30 ft wide can be fully illuminated by natural light during almost all daylight hours by admitting light through both the opposing walls. For a building up to 60 ft wide, it is feasible to admit enough natural light through the walls to fully illuminate the perimeter zones (within 15 ft of the walls) and provide half of the illumination in the core of the building. Supplying natural light deeper than 30 ft from the light-admitting wall typically requires very high ceilings or some more aggressive daylighting system, such as using mirrors to project beam sunlight into the core of the building. For such large floor plates, it is usually most economical to focus on designing a very efficient electric lighting system for the spaces more than 30 ft removed from the light-admitting walls.

In general, the preferred orientation for the building is with the major façades oriented toward the north and the south. Accuracy in establishing the façade orientations is critical. Thermal loads and glare increase rapidly as the façade orientation moves away from directly south and directly north. The combination of north and south glazing provides more light and heat during the heating season than during the cooling season, which serves the thermal goals of the building. In contrast, orienting the primary walls toward the east and west typically admits between two and three times as much light and heat during the cooling season as during the heating season, which is definitely not the desired energy balance.

While it is understood that the architect typically makes most of the decisions regarding the building massing, building orientation, and façade design, it is often the case that well-informed specialists on the design team can "nudge" these decisions in the correct direction. The better informed that all the members of the design team are, the more likely it will be that the correct decisions will be made.

Accommodating Daylighting

An effective approach to system integration is outlined in the following points:

- Beams running parallel to the light-admitting wall have a greater obstructive influence in blocking light entering through the wall than do beams running perpendicular to the light-admitting wall. Therefore, it is particularly desirable to keep the beams running parallel to the light-admitting wall shallow.
- The more heavily loaded a beam is, the deeper the beam tends to be. Joists carry a lower load per unit length than do girders. Therefore, for a given span, joists are typically shallower than girders. This suggests that, for daylighting purposes, the joists should run parallel to the light-admitting wall and the girders should run perpendicular to the light-admitting wall.
- To make the joists even shallower, it is desirable to use them in composite action with the floor slab.
- To take advantage of the shallowness of the joist, it is important that the ceiling be set as close to the bottom of the joist as possible. Because the girders will be deeper than the joist, this implies that the ceiling must be placed between the girders, rather than below the girders.
- Keep the spans of the joists reasonably short, so that their depth can be shallow. However, there is a limit to this process: a short span for the joists implies a close spacing of the supporting girders. Even though girders run generally parallel to the direction of the daylight movement, much of the daylight is not moving directly perpendicular to the light-admitting wall, but rather is moving into the

space at an angle. Much of this angled light will encounter the deep girders, which will absorb some of the light and scatter some of the light in an undesired direction. The closer the spacing of the girders, the more frequently these encounters will occur and the greater the interference to the light penetrating into the space. Spacing the girders closer together also means there will be more columns to interfere with light entering through the daylight wall.

Figure 3 provides an example, a building that is 60-ft deep from the south daylighting wall to the north daylighting wall. The floor joists are parallel to the daylighting walls and the girders are perpendicular to the daylighting wall. Both the joists and girders span 30 ft.

The floor deck is lightweight concrete in composite action with 2-in.-deep corrugated steel decking, with an overall slab thickness of 6 in., chosen to limit vibrations and for fire rating purposes. At a 30-ft span, the chosen floor joists are 12-in.-deep wide-flange beams used in composite action with the concrete deck, using ¾-in.-diameter, 4-in.-long shear studs. Floor diaphragms absorb the wind forces on the walls and transfer them to the lateral bracing elements.

Lateral bracing for resisting forces in the north-south direction is located in the east and west walls, which are not regarded as primary sources of daylight. Lateral bracing for resisting forces in the east-west direction is located at the centerline of the building, where it will interfere least with the movement of daylighting into the building.

The cutaway view shown in Figure 4 illustrates how this framing system can be integrated with the other subsystems. Specifically, it shows:

- The floor plenum, with access floor supported on pedestals.
- A supply air system (shown in red), consisting of a vertical supply shaft from the air-handling units at the bottom of the building, horizontal manifold ducts, and supply ducts delivering air to the various parts of the floor plenum. Delivering air to remote parts of the floor plenum through insulated ducts assures that the thermally conditioned air gets everywhere without degrading the quality of the thermal conditioning. These ducts have to pass between the pedestals supporting the access floor, which sets a limit on how low the plenum volume can be.
- A cutaway view of the concrete floor deck on top of the joists.
- A cutaway view of thermal insulation on top of the concrete floor deck. This provides thermal separation between the supply plenum in the floor above and the return plenum in the ceiling below. Without this, the concrete slab has the potential to act as a huge counter-flow heat exchanger.
- A cutaway view of the ceiling, which is mounted just below the joists.
- The steel joists mounted on the top of the steel girders.
- The steel joists extending beyond the end girder.
- A return-air system (shown in blue), consisting of the ceiling plenum (between the joists), horizontal manifold ducts, and a vertical chase that transports return air back to the air-handling units at the bottom of the building.

The deep girders running north-south under the floors tend to interfere with the transport of thermally conditioned air along the length of the building (i.e., in the east-west direction). To facilitate both the free flow of return air above the ceiling and keeping the ceiling high, the girders have been placed below the joists. This arrangement allows the air to pass up through the ceiling and then return between the joists above the ceiling. Mounting the joists on top of the girders is a slightly unconventional framing scheme that requires some additional care to avoid web buckling in the joists and will also require some additional framing to connect the floor diaphragm to girders that are part of braced frames providing lateral stabilization for the building.

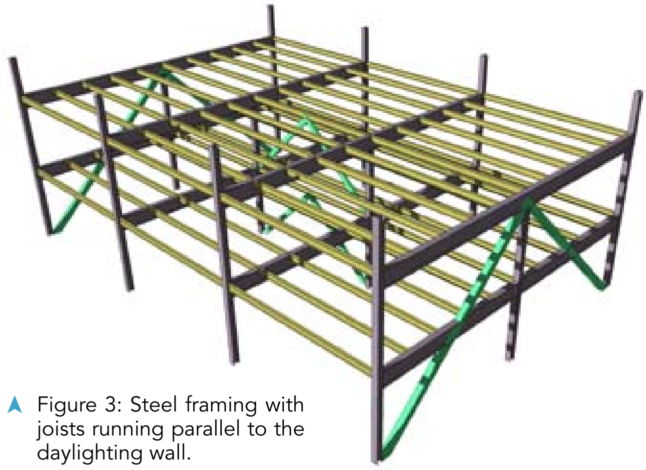

Figure 3: Steel framing with joists running parallel to the daylighting wall.

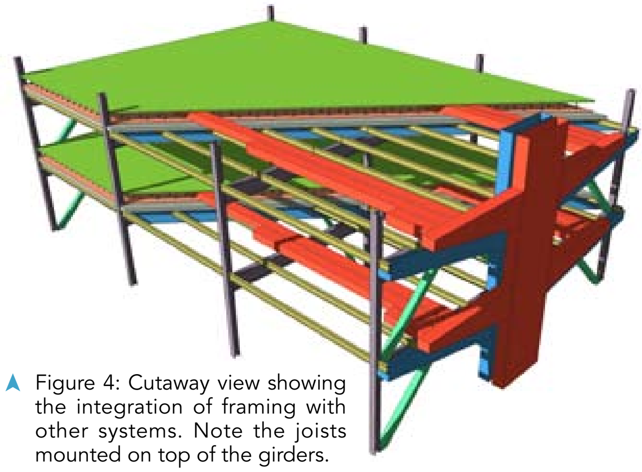

Figure 4: Cutaway view showing the integration of framing with other systems. Note the joists mounted on top of the girders.

Practical Application

The North Carolina Wildlife Conservation Commission Headquarters and Exhibition Building, depicted in Figure 2, was the first building in which the integrated system described above has been applied. The design issues and goals for the building were as follows:

1. The intended size of the building and the constraints of the site required a building six stories high, with walls as the primary sources of daylight for the building interior.
2. The site is reasonably free of solar obstructions.
3. The orientation of the site accommodates the elongation of the building in the east-west direction, permitting most of the glazing to be put on the north and south walls.
4. In planning the building, thought was given to zoning of

spaces to accommodate the uneven distribution of illumination inherent in side-lighting systems. For example, elevators and restrooms were placed at the core of the building, where the light level is naturally lower.

5. The decision was made to limit the north-south dimension of the building to about 60-ft to avoid having core spaces too far removed from the daylighting sources.
6. An 11-ft, 2-in. floor-to-ceiling dimension was maintained everywhere for transmitting light into the building.
7. The overall floor-to-floor dimension was 14 ft, 6 in.

Figure 5: A perimeter office in the North Carolina Wildlife Conservation Commission Headquarters and Exhibition Building, Raleigh, N.C.

Figure 6: The south façade of the North Carolina Wildlife Conservation Commission Headquarters and Exhibition Building, Raleigh, N.C.

The building has been occupied since September 2005 and is the topic of several ongoing post-occupancy evaluations. It already has established a reputation as a model of energy efficiency and systems integration, although some systems commissioning issues and energy performance measurements are still under way. While the final energy performance data are not yet available for an entire year of operation, the effective integration of structure, HVAC, and daylighting systems has been clearly demonstrated by the project.

Spandrel Beams

In addition to the systems integration issues outlined above, another structural issue requires some care to protect the performance of the daylighting system. We often put deeper beams at the perimeter walls. This decision may be motivated by concerns for the glass or other brittle envelope materials, such as brick, that do not tolerate large deflections in the support beams. The decision may also be prompted by a desire to use deep spandrel beams as part of rigid frames to resist lateral forces on the structure.

To prevent deep perimeter beams from interfering with the admission of daylight, the deep spandrel beam can be located at least partially above the floor slab, as shown in Figure 7. Daylight admitted near the floor makes a negligible contribution to the performance of the daylighting system, so we typically want to make the portion of the wall up to about 3 ft above the finished floor an insulated, opaque wall. This affords the structural opportunity to incorporate extremely deep spandrel beams or even deep spandrel trusses.

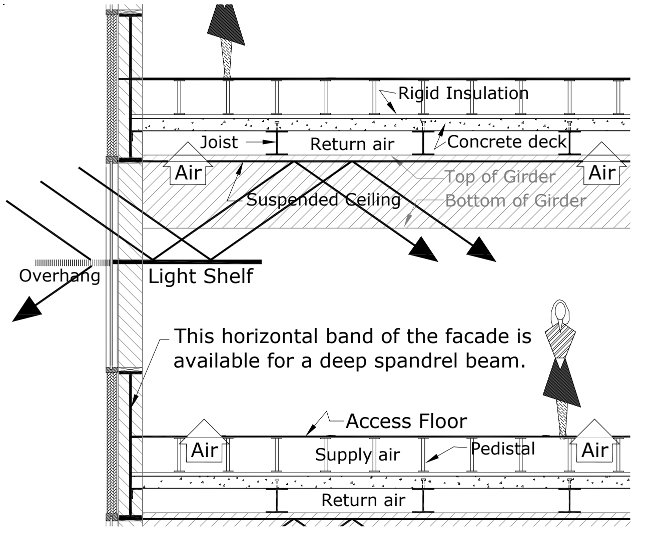

Figure 7: A deep spandrel beam mounted partially above the floor.

Integration Equals Opportunity

Solutions such as these point to the fact that reducing the environmental impact of a building should not be addressed solely in individual areas or systems—structural, lighting, HVAC, etc.—but also in combination. When this thought process is followed, it greatly expands the structural engineer's potential contribution to a building's energy efficiency and environmental footprint. MSC

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