

Modular Skylight Systems: Best Practices for Designing Skylights with Suspended Ceilings

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ABSTRACT

This paper describes the concept of modular skylight wells that can be pre-manufactured, are easy to install, and can gracefully integrate skylights with suspended ceilings and other building components. A modular skylight system consists of a two-part light well system using a throat and a splay. The throat is the upper part of the well directly below the skylight. Its primary purpose is to channel light efficiently through the plenum. The splay is the lower part of the well, which connects to the ceiling. It increases illuminance uniformity, shields the bright source, reduces contrast ratios and provides an aesthetic transition between light well and ceiling.

Since modular light well products do not currently exist, the market transformation effort is a two part process: 1) providing market research and performance specifications for manufacturers; and 2) informing architects of the desired features of skylighting and modular light wells. The end-product of this effort is the California Energy Commission (CEC) document, *“Modular Light Wells: Design Guidelines for Skylights with Suspended Ceilings”* (CEC 2003), a study conducted for CEC’s Public Interest Energy Research program (PIER).

This paper summarizes some of the key elements of the PIER research including:

- A new paradigm for technology development
- Estimates of potential market size and energy savings from modular light wells
- The nomenclature and definitions of common light well functions and components
- Considerations for integrating skylights and light wells into building design and construction
- Design recommendations for optimal energy performance and lighting quality
- Conceptual examples of a modular skylight system

Introduction

Currently, there is an increasing demand for daylight in low-rise buildings such as retail stores, office complexes and schools. Skylighting, a simple and reliable method of daylighting, is being successfully applied to a wide range of buildings that have suspended ceilings. More and more retailers are starting to include skylights in their stores. Educators are looking for ways to bring daylight into classrooms. Office building owners increasingly believe that the provision of daylit workplaces is likely to increase the value of their buildings. When skylights are installed in commercial buildings with suspended ceilings, a light well is needed to provide a path for the light to travel between the skylight and the opening in the ceiling. The advantages of skylights and suspended ceilings in commercial buildings are described below.

Skylights

Skylights provide better lighting quality and more reliable energy savings than daylight designs relying solely on windows. A good skylight design provides relatively uniform

illumination through a space while introducing variation in the appearance of the space over the course of a day and season. Recent research also links improved productivity and increased retail sales with daylight (HMGa.1999, HMGB.2003, HMGc.1999).

Skylights produce whole-building energy savings by reducing the need for electric lighting during the day and also by reducing the need for cooling to counter the heat gain from those electric lights. To achieve energy savings with skylights, the electric lights must be turned off or dimmed down during daylight hours, which is best done automatically by photocontrols that sense ambient light levels and adjust electric light levels accordingly. The skylights must also be appropriately sized to provide optimum lighting conditions while avoiding excessive heat loss or heat gain.

Suspended Ceilings

The simple modular nature of a suspended ceiling system provides many architectural benefits to commercial buildings such as building flexibility facilitating tenant changes in office and retail spaces, while reducing ceiling height, reducing the effective volume of conditioned space and bringing the lighting and ventilation delivery systems closer to the occupants.. A typical suspended ceiling (otherwise known as finished ceilings, t-bar ceilings, acoustic tile ceilings and modular ceilings) consists of regular grid system which allows several building systems to be easily organized with minimal coordination effort (like heating and cooling vents, luminaires, fire sprinklers, audio speakers, structural systems, and plumbing, electrical and mechanical supply). The regular repeating pattern and finished surface is an expected form and aesthetically pleasing. The sound absorbing surfaces of ceiling tiles can provide acoustic insulation improving productivity in workplaces and verbal learning performance in schools. Hence, suspended ceilings systems are considered the preferred solution in many commercial building environments.

Potential for Skylight Systems with Suspended Ceilings

The potential market for skylight systems includes building types that can take advantage of skylight design and that require the use of suspended ceiling systems. These are typically low-rise commercial buildings, such as offices, retail spaces, grocery stores and schools. Together these four building types make up 54% of all new and retrofit construction square footage in California. With an estimated annual commercial construction volume of 156.5 million square feet (sf) per year in California (Brooks 2002), these occupancies account for approximately 84.8 million sf of new construction. The U.S. national construction volume is estimated at 1,109 million sf annually. Educational, retail and office spaces make up 543 million sf, or 49% of commercial construction volume nationwide (EIA 1999).

The market size for skylights can be determined by the amount of floor area that can be installed with skylights; that is, area that is directly under a roof. Figure 1 (EIA 1999) suggests that 68% of all new non-residential floor space is directly below a roof, and that could potentially be installed with skylights. With national new construction of office, retail and educational space at 543 million sf a year, the potential market for skylight installations is 369 million sf of floor area annually (68% of total area).

Suspended ceiling systems are installed in 68% of all educational facilities, 45% of all office space and 46% of all store floor space (Armstrong World Industries, 2002).

**Figure 1. New Construction Floor Area under Roof in the United States
(Annual Average from 1990 to 1999)**

| Floors | Total Area (Million SF/yr) | Fraction of Total | Area Under Roof (Million SF/yr) | Fraction Under Roof |
|--------------|-------------------------------|----------------------|---------------------------------------|------------------------|
| One | 563 | 51% | 563 | 51% |
| Two | 266 | 24% | 133 | 12% |
| Three | 97 | 9% | 32 | 3% |
| 4 to 9 | 132 | 12% | 22 | 2% |
| > 9 | 51 | 5% | 3 | 0% |
| Total | 1,109 | 100% | 754 | 68% |

(Source: EIA, 1999)

Figure 2 shows that approximately 16.5 million square feet of commercial space built each year can use integrated skylights and suspended ceilings within California alone (with 121 million square feet of area nationwide that can potentially integrate skylights with suspended ceilings). Figure 2 also illustrates the potential energy cost savings in California alone from installing skylights in the five targeted building types, considering only those spaces that are directly under a roof, that have T-bar ceilings (suspended ceilings) and for which skylights are likely to be feasible. If photocontrols are used to reduce electric lighting energy whenever there is sufficient daylight from skylights, in California alone, one year's worth of new and retrofit construction could save California ratepayers approximately \$3.2 million/yr. This figure when replicated to buildings in the entire US, would result in approximately \$23.8 million/yr of electricity savings nationwide (CEC, 2003).

**Figure 2. Energy Cost Savings Potential from One Year's New/Retrofit
Construction for Five Selected Building Types in California**

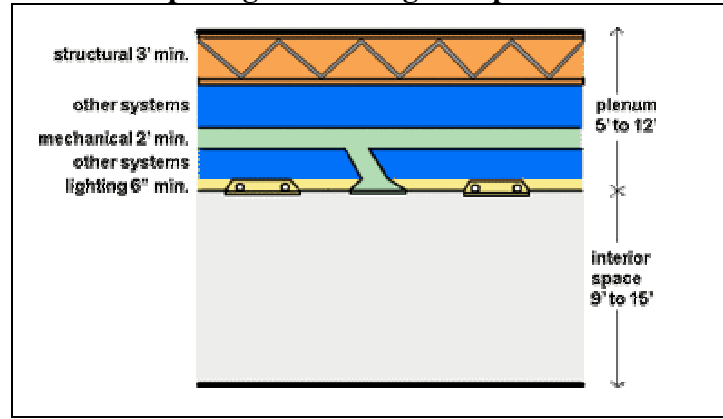
| Occupancy | New or Retrofit M SF/yr | Area Under Roof | Percent Suspended Ceiling | Feasible | Total Million SF/yr | Cost Savings \$/SF-yr | Annual Savings (\$Millions) |
|---------------|-------------------------------|-----------------------|---------------------------------|----------|---------------------------|-----------------------------|-----------------------------------|
| Lg Office | 30.9 | 35% | 45% | 50% | 2.4 | \$ 0.15 | \$ 0.4 |
| Sm office | 9.9 | 50% | 45% | 50% | 1.1 | \$ 0.15 | \$ 0.2 |
| Grocery | 6.6 | 100% | 46% | 75% | 2.3 | \$ 0.23 | \$ 0.5 |
| Retail | 24.8 | 80% | 46% | 75% | 6.9 | \$ 0.23 | \$ 1.6 |
| Education | 12.6 | 60% | 68% | 75% | 3.9 | \$ 0.16 | \$ 0.6 |
| Totals | 84.8 | | | | 16.5 | | \$ 3.2 |

Barriers in Current Practices

Current building techniques typically use custom-designed, site-built skylight wells. However, onsite construction can compromise construction quality, and building aesthetics. There is little control on daylight distribution into interior spaces. Skylight well parts often need to be special ordered, re-cut or re-bent during construction, thereby increasing labor, cost, and design and installation time. This can result in considering skylights and suspended ceilings to be incompatible. Adding skylight wells requires a new method of building component integration with vertical and horizontal building layers. Current practice allocates a "strata" from structural members near the roof deck, to a mechanical layer, followed by sprinklers and then lighting just above the ceiling. A skylight well cuts through all of these strata (see Figure 3). If the light well and other layers of the strata are not coordinated well, this can result in substantial delays. The space of skylights is dictated by the structural grid. The edges of the skylight land on secondary

and tertiary structural members. Rarely will the structural grid be aligned with the ceiling grid. Thus the light well must be designed with some provision for horizontal offsets, and this can make for some awkward light well designs.

Figure 3. Typical Vertical Spacing of Building Components between Roof and Ceiling



(Source: Heschong Mahone Group, Inc)

There are some pre-manufactured systems like tubular skylight systems, that allow various angles and lengths, and which culminates in a light diffuser mounted at the ceiling plane. However, the tubular skylights are substantially smaller than the site-built systems, and currently do not incorporate a splay. As a result, for the same space, many more tubular skylights are needed to provide the same amount of useful daylight.

The custom-designed and site-fabricated skylight wells thus result in uncertainty regarding its cost, performance, compatibility, and quality. This is an unfortunate market barrier as skylighting is the most reliable approach for obtaining energy savings from daylighting.

Overcoming Barriers: Modular Light Well Systems

Given the growing demand for daylight in buildings, and given the pervasive use of suspended ceilings, there is likely to be a growing demand for systems that facilitate the marriage of these two systems. A splayed modular skylight system offers designers the option to circumvent the issues discussed above. This system is developed around the concept of a two-part light well system using a throat and a splay (see Figure 4). The throat is the upper part of the well directly below the skylight. Its primary purpose is to channel light efficiently through the plenum. The splay is the lower part of the well, which connects to the ceiling. The primary purpose of a splay is to improve light distribution and overall lighting quality in a space. It can also reduce the cost of a skylighting system by allowing fewer, larger skylights within a space for a given amount of daylight illuminance and energy savings.

A modular skylight well system that simplifies the incorporation of skylights into buildings with suspended ceilings will increase the opportunities for building design with both skylights and suspended ceilings. Without such a system, building owners and designers are likely to choose one or the other to avoid the extra cost of custom design and fabrication.

A modular skylight well that easily and efficiently connects a skylight to a suspended ceiling system is essentially a new product that has not had a clear presence in the construction industry. While there are currently a few commercially available products that might be

considered “modular skylight wells” they are not categorized within the formal structure of the construction industry and do not have a number in the CSI (Construction Specification Institute) specification system. There is no common terminology to discuss the product and its performance. There is not a shared understanding of product performance criteria and manufacturer responsibilities. Currently there are no ICC (International Code Council) evaluation reports and designers don’t have readily available information on the safety of light wells.

Figure 4. A View of a Grocery Store with Splayed Skylights Made of Acoustical Tiles



(Source: Heschong Mahone Group, Inc)

A New Approach to Public Funded Research

The Public Interest Energy Research program (PIER) of California Energy Commission (CEC) funded a research project headed by Heschong Mahone Group, Inc involving integration of Skylighting system with ceilings in low-rise commercial buildings. The result of this project is put together in a document “*Modular Light Wells: Design Guidelines for Skylights with Suspended Ceilings*” (CEC 2003), described in this paper as *PIER Design Guidelines*. The research team had identified that modular skylight wells would result in a significant energy savings and societal benefits.

We developed a different model to solve this problem than traditional government sponsored applied research programs. Typically research is conducted by a lab in partnership with a selected company and a propriety product is developed. In contrast, we researched the market potential and functional requirements for modular light wells. This we reported back to a technical advisory group of manufacturers, architects, lighting designers and utility groups.

We were essentially using public resources to develop a feasibility analysis of modular light wells. This reduces the risk to companies for investing money in a preliminary feasibility study that might not result in a product. We had provided the ground work for manufacturers on the benefits of the technology, how much it can expect to save per product, the magnitude of the market and the functional requirements of the product. We also provided manufacturers with product delivery options—fabricating only one or two components of the system and integrating

with other manufacturers providing other components, or providing the whole modular light well system as a kit of parts.

For the consumers (building designers), we had provided a description of the benefits of the products, a nomenclature for product components and features, and functional specifications. We also provided the team with guidance on how to design with skylights and how to coordinate light wells with the rest of the building components. The following contents of this paper briefly describe aspects of the *PIER Design Guidelines* that promotes easy installation and design of modular skylight systems.

Criteria for a Modular Skylight Well System

The design quality of a skylight system has a profound effect on its efficiency and effectiveness. The fundamental components of an effective modular skylight system include the five design principles (described below): 1) Lighting quality, 2) Energy savings, 3) Dimensional adjustment, 4) Construction coordination, 5) Safety and verified performance.

Lighting Quality

The main purpose of a skylight system is to provide useful light in workspaces. Skylights should provide adequate, uniform illumination with minimum glare. They should produce gentle variation in brightness among adjacent surfaces while eliminating excessive contrast between them. Daylight from skylights should meet the same criteria for lighting quality as required for electric lighting systems. Chapter 10, in the 9th edition of the Handbook of the Illuminating Engineering Society (IESNA 2001) provides a summary of electric lighting quality criteria. The throat and splay system allows more uniform illumination, reduces contrast ratios and provides an aesthetic transition between light well and ceiling.

Energy Savings

The energy savings from a skylight system involves trade-offs between lighting, cooling and heating consumptions. The SkyCalc software is a simple, easy to use tool that quickly identifies the trade-offs. Often building simulation tools like DOE-2 or EnergyPlus can provide more precise results but may need more effort to develop the model. Skylight buildings require photocontrols to save energy. Photocontrols turn off or dim electric light in response to available daylight. The *PIER Design Guidelines* (CEC 2003) provides an overview of photocontrol application issues and the *Photocontrol Guidelines* (HMGg, 2003) provides more detailed information.

Dimensional Adjustment

Skylight wells connect between skylight openings positioned to the structural grid of the roof and ceiling openings positioned in the suspended ceiling grid. The roof and ceiling grids seldom match. In addition, all roofs including flat roofs have a minimum slope. This means that the plenum space between the ceiling and roof continuously changes over the span of the roof. Within the plenum the vertical penetrations of skylight wells may conflict with the horizontal runs of other buildings systems. Moreover, the space below the finished ceiling may be

remodeled, which may alter the height and/or position of the ceiling grid. Flexible well designs that can adjust up to a foot in any horizontal direction and four feet in the vertical directions should resolve these conflicts. Flexible connections can also provide construction tolerances of up to two inches to resolve dimensional inconsistency in finished surfaces.

The throat and splay system is one way to provide construction flexibility, thereby reducing conflicts with other systems. The system allows dimensional adjustments between roof and ceiling grids. The connection between the throat and splay provides for final construction tolerances. In addition, manufacturers can prefabricate the components to be compatible with each other. Prefabricated components can be installed in phases to accommodate other on-site schedules. A system of interconnecting, adjustable modular parts provides a great range of design options, reduces handling and installation costs and may accelerate wider use of skylights in buildings with suspended ceilings.

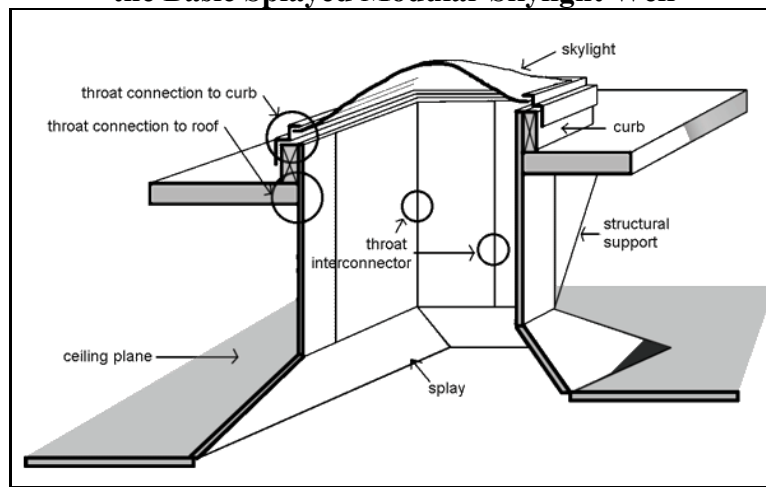
Construction Coordination

All professions and trades involved in construction need to be informed of the plenum, ceiling and roof spaces to be occupied by skylight wells. Skylight well installations should coordinate with construction schedules for other systems. Installation information should fit into the industry's standard communication channels. Once installed, the wells need to be protected until all construction is complete.

Safety and Verified Performance

A skylight well system must also address applicable building safety standards. This includes fire ratings, insulation locations and seismic ratings. Architects and building owners should be able to predict the performance of these systems via verified testing protocols.

Figure 5. The Throat and Splay with a Structural Supports and Connector System Form the Basic Splayed Modular Skylight Well



(Source: Heschong Mahone Group, Inc)

Nomenclature for Modular Light Wells

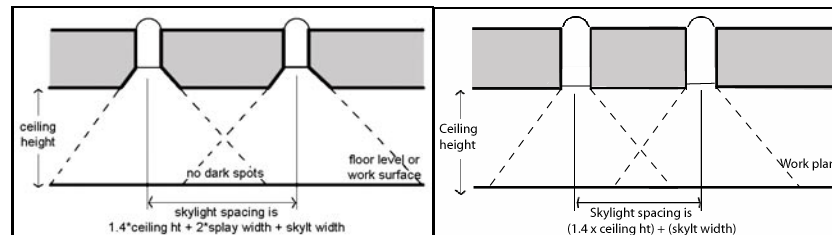
Introducing a nomenclature and definitions for common light well functions and components can be used as a common vocabulary in the entire skylighting industry. The *PIER*

Design Guidelines (CEC, 2003) addresses a nomenclature, defining each component of a modular Skylighting system. These definitions of parts allow manufacturers and designers to precisely describe components. The *PIER Design Guidelines* (CEC, 2003) identifies and defines each and every part of the entire skylight well system. For example, the *PIER Design Guidelines* defines a “throat-interconnector” (see Figure 5) as a component that attaches two pieces of throat material (maybe gypsum, or tiles etc). It may be a rigid or adjustable connection that allows for vertical, horizontal or angular displacement of the throat.

Optimizing the Design Process

The skylight well design is an iterative process that begins with simple assumptions and rule-of-thumb guidelines. It is then refined through more comprehensive design analysis and feedback on interaction with other building systems. The *PIER Design Guidelines* and the *Energy Design Resources* describe in detail the design process and easily understandable tips to achieve best comfort conditions within a skylit space. Simple rules of thumb for sizing and spacing of skylights (see Figure 6) and understanding the advantages of splays versus no splays, help designers to solve some of the design issues. The simple design process involves steps to maintain visual and thermal comfort by giving design tips like optimum light transmittance and uniform light distribution. Design tools like Advanced Lighting Guidelines (NBI 2003) available via download, provides general guidance on design and specification for both electric and daylighting systems. Skylighting Guidelines (HMG 1998) available via free download, provides skylight design guidance for engineers and architects. SkyCalc®, a sophisticated Microsoft Excel spreadsheet, estimates annual whole building energy savings and illumination levels for various skylight systems.

Figure 6. Skylight Spacing for Splayed (Left) and Unsplayed (Right) Skylights



(Figure indicates that to provide the same amount of illumination, unsplayed skylights need to be placed closer than splayed skylights. Source: Heschong Mahone Group, Inc)

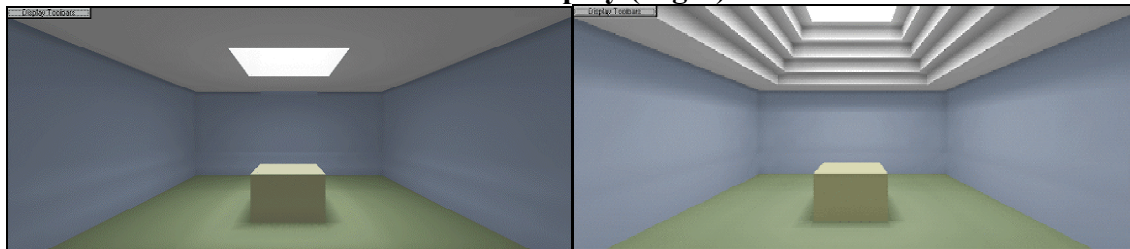
The use of photometric analysis and photometric files for skylights allows the designer to visualize the pattern of light in the space (HMGf, 2003). In Figure 7, simple illustrations rendered in LumenMicro illustrate how a splayed ceiling increases the distribution of light in space. Photometric files for skylights are now available at www.newbuildings.org/pier/index.html or at www.h-m-g.com.

Component Performance Criteria

Each component of a skylight system should satisfy minimum performance goals and have design options based on illumination, energy, fire-safety, structural integrity and assembly

sequence. Specification is essential for the unit skylight, skylight glazing, throat, splay, daylight controls, electric lights, electric light controls, suspended ceiling and other building components affecting a skylight installation. The *PIER Design Guidelines* and the *Energy Design Resource Design Brief* (EDR, 2004) describe the component specifications of all parts of a light well system.

Figure 7. Light Distribution in a Space with Skylight without Splay (Left) and with Splay (Right)



Source: Lighting Technologies

As an example, a throat surface can be specified in the following ways. Common throat surfaces include gypsum board, sheet metal, various mylar-coated fabrics, insulating composite boards, and acoustic tiles. Gypsum board provides seamless corners, but is heavy, inflexible, and requires extra labor for a finishing surface. Acoustic tiles are easy and cheap to install, but inflexible to plenum adjustments and need laborious site installation. So, the throat surface can be specified as being highly reflective, thin and lightweight, and compatible with rectangular skylights and ceiling grids. The throat could have flexibility to navigate around other systems occupying the plenum and provide for construction tolerances and lateral displacements. It should also serve as a fire and smoke resistant, an acoustic buffer between the plenum and interior spaces, and an attachment surface for other systems such as fire sprinkler heads, light controls, diffusers or electric lights. The throat structure must also meet structural and seismic requirements.

Conceptual Examples

Four conceptual examples illustrated in

Figure 9 offer potential design solutions for design and construction requirements of modular skylight systems. It is hoped that the conceptual diagrams and descriptions of these example systems provide inspiration for innovation by both designers and manufacturers to create new solutions and products to meet the needs of skylight buildings. The four systems are:

- System 1—Pivoting Threaded Rod (Fixed Splay) System
- System 2—Fixed Metal Throat (Adjustable Splay) System
- System 3—Tubular Adjustable Throat (Fixed Splay) System
- System 4—Fixed Throat Flexible Connector (Fixed Splay) System

Figure 8. Types of Skylight Wells: Tubular Skylights (Left) and Acoustic Tiles Skylights

These four systems each provide a possible solution to one of the central challenges of a skylight well placed in a suspended ceiling system—that of accommodating the dimensional shifts between skylight opening and well opening. Although in the best of all worlds, skylight wells would always be located precisely underneath the skylight opening, in reality there are many reasons why there will be some degree of offset between the skylight and the well opening, including:

- Roof decks at a slope for water drainage while ceilings are truly horizontal
- Actual ceiling installed (or retrofitted) at a slightly different height than specified
- Well opening located at two foot modules of ceiling grid, while skylight openings are located on structural modules that vary
- Skylights placed in original shell construction by owner, while ceilings are installed (or retrofitted) much later by tenant, and
- Other major building element (such as beam, column, duct, pipe, light fixture) must occupy preferred location for skylight well, so well location must shift to accommodate

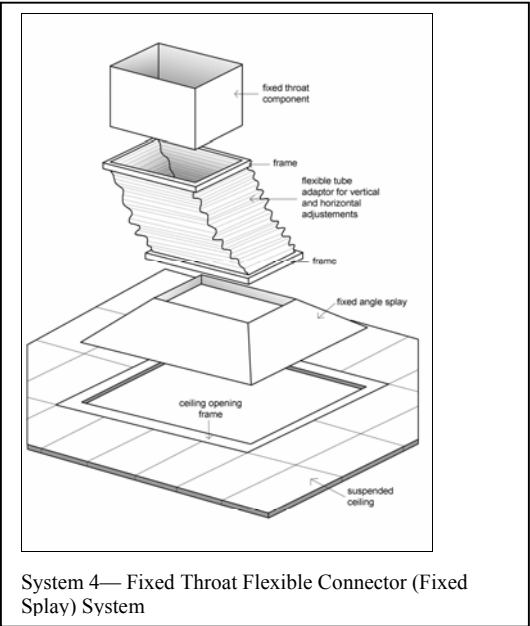
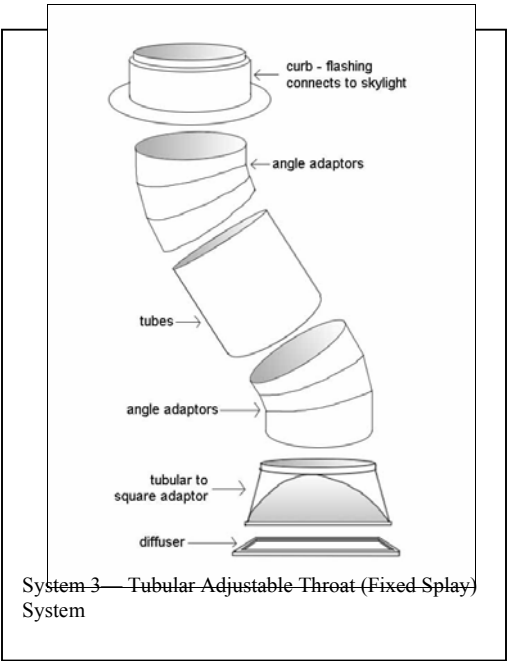
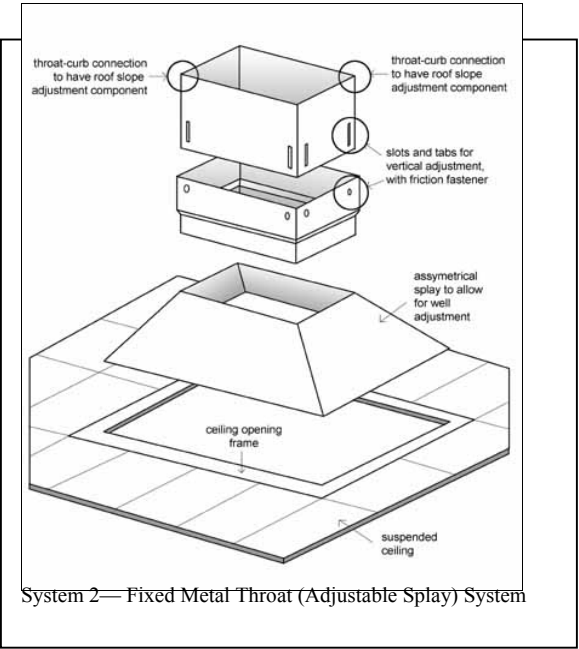
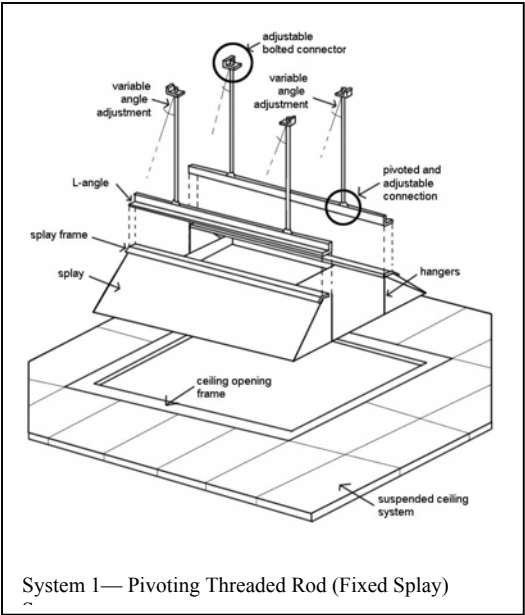
In addition, each system addresses other construction realities. They differ in how they indicate to other trades the space which must be reserved for the skylight well, how they protect important finish surfaces during construction, such as the light reflective surfaces of the throat, and how they stage construction so that all parts and systems are accessible when needed for installation or maintenance.

Conclusions

The solutions presented here are based on research results (site survey results and market research), as well as input from industry members and architects and designers who have installed or designed skylight wells with suspended ceilings. In addition to superior lighting quality, higher energy efficiency, improved occupant comfort and lower installation costs, splayed modular skylight systems can create beautiful, daylit, architecturally pleasing spaces. As a new concept, they can solve many issues faced by designers who wish to provide daylight in large, low-rise buildings.

Architects, retailers, school and building owners have an interest in adopting such a prefabricated system that can easily integrate with suspended ceilings. Manufacturers in the skylighting industry can benefit from modular skylight product components requirements and codes and performance metrics for their product evaluation. They can all benefit from a system that guarantees performance, reduces design and specification time, and can be fed into standard information channels used for other construction products. The modular skylight wells can result in a new paradigm for technology development and transform their market feasibility.

Figure 9. Four Conceptual Sketches of Modular Skylight Systems



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