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Time	**Beta 1 Room:** Low Energy Architecture Chair: Prof. Dr. Joseph Khedari, RCSEE, RMUTR, Thailand Co-Chair: Dr. Withaya Puangsombut, RCSEE, RMUTR, Thailand		
13:00-14:45	Paper's Title	Authors	Country
13:00-13:15	Experimental Rotating Room for Daylighting Studies	L.O. Beltrán	USA

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Experimental Rotating Room for Daylighting Studies

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Abstract

This paper presents the design, development and construction process of an experimental rotating room to study the performance of complex fenestration systems (CFS). The room, of 600 ft^2 represents a workspace of 20 ft wide, 30 ft deep and 11 ft high with two windows 9' wide by 5' high. The room was built with Structural Insulated Panels (SIP) over a metal structure on four casters that can rotate 360 degrees around a central axis. The room has high performance windows, automated external louvers, energy efficient lighting, lighting controls, DALI controller, and a horizontal passive solar light pipe system. Data collected in this facility will serve to evaluate the energy consumption and lighting performance of integrated building technologies. Visual comfort will be assessed at different viewpoints in the testing room to detect glare, contrast, and compare them with occupant's responses.

Keywords: Daylighting, Energy Savings, Glare, Light Pipe, Scale Models.

Background

Current lighting programs are not able to accurately simulate the lighting performance of CFS designs such as the solar horizontal light pipe that we had recently developed. Our light pipe system has a complex geometry and uses unique optical materials along its collector, transportation and distribution sections. Some computerized lighting programs use Bidirectional Reflectance Distribution Function, (BRDF) and Bidirectional Transmittance Distribution Function, (BTDF) to accurately predict the distribution of light in interior spaces; however, the optical properties of the films used in our light pipe have not been measured by manufacturers or laboratories yet. These measurements (BRDF and BTDF) require the use of expensive and sophisticated equipment, such as gonioreflectometers and goniophotometers, which have to be operated by highly trained specialists. Therefore to get the optical properties of new materials became extremely expensive.

Researchers have been developing several methods to predict the lighting performance of their optical light pipe designs without a comprehensive validation of their predictions.

- Development of mathematical algorithms to predict the lighting performance of vertical [1, 2, 3, 4] and horizontal [5] light pipe designs.
- Short term measurements in existing spaces with commercial vertical light pipe prototypes to characterize their lighting performance [6, 7].
- Use of small physical scale models to evaluate the lighting performance of horizontal light pipe designs at specific times of the year [8, 9, 10].
- Use of large scale models (1:4) to evaluate the lighting performance of a light pipe design throughout an entire year [11, 12].
- Use of computer programs such as Radiance to model and evaluate some horizontal light pipe designs [13, 14. 15], and some vertical light pipes [16, 17, 18].
- Researchers at Faunhofer Institute in Germany have developed a forward ray-tracing module for the Radiance lighting program: Photon Map. These algorithms were implemented in an older version of Radiance (3.6) and have not been updated to the current 4.0 version. Photon Map only runs in UNIX, it does not have a user friendly environment and lacks of material libraries. Other lighting programs have been developed with powerful ray-tracing algorithms (i.e. ASAP, Apilux, TracePro and Photopia) that promise more accurate results but presently they have a limited material libraries. At the present time, none of the above simulation procedures can be used to accurately predict the lighting and energy performance of our horizontal solar light pipe; the best option is to test our light pipe in a full-scale space. The use of computer programs to model and accurately evaluate CFS' performance has great potential in a near future; however, more testing and comprehensive validation needs to be performed to have a reliable CFS design tool where new optical materials could accurately be modeled and tested.

Description

The design of this facility is the result of a long search of reliable simulation tools that can accurately evaluate new envelope technologies. This paper presents a unique low cost 360˚ rotating experimental room to accurately evaluate CFS. The 600 ft^2 experimental rotating room, located at the Architecture Ranch site at the Riverside Campus of Texas A&M University was built to test, to develop, and to integrate new environmental technologies.

The experimental rotating room is part of a funded research project sponsored by the US Environmental Protection Agency, EPA-P3 program. Our research project was awarded with two EPA P3 grants (Phase I and II) to develop core sunlighting technologies to reduce energy consumption and improve lighting efficiency in multistory deep floor plan office workspaces.

METHODOLOGY

The design of this facility has been developed progressively during several years, in which multiple simulations tools were examined and refined through comparative analysis of accuracy, costs, construction materials, information recorded, and benefits. To evaluate our CFS performance, we have used the following tools.

A. Small scale models

Physical scale models are commonly used by architectural designers to make important decisions throughout the design process. To evaluate the lighting performance of our light pipe in architectural spaces daylighting models were used. Daylighting models are built in scales that range from 1:15 to 1:25, with precise interior surface reflectance, and window details. We built a 1:20 scale model of an office space with dimensions of 20 ft in width, 30 ft in depth, and 10 ft in ceiling height, with removable window wall and ceiling to test alternate designs of optical light shelves and light pipes [8, 9] (Fig. 1). The interior surface reflectances were: ceiling 0.76, walls 0.44, and floor 0.21. The window had a clear glass of 0.88 visible transmittance (VT). Model testing was done on the roof of the College of Environmental Design at U.C. Berkeley campus.

B. Large Scale models

To predict, quantify and compare the lighting performance of our CFS, two scale models at 1:4 scale were built, one as a reference model (RM) and the other as a test model (TM). The two scale models simulated south-facing deep open plan office spaces of 10 ft high, 20 ft wide and 30 ft long. The RM introduced daylight only through sidelight windows, while the TM received additional daylight through the horizontal light pipe. The models were placed on the roof of the College of Architecture building at Texas A&M campus (Fig. 2). In both models the interior surface reflectance were 0.8 for the ceiling, 0.47 for the walls, 0.23 for the floor, and 0.34 for the office furniture and photometric sensor holders. The windows represent double-pane spectrally selective low-E glazing with closed white Venetian blinds, with VT of 77% and 20% respectively; with an overall VT of 15% (Overall VT = Glass VT x Blinds VT). The models use clear glass (VT=88%) and three layers of diffusing white paper; with an overall VT of 14%. In order to have visual access to the models, three viewports at eye level (5 ft) were provided on each scale model: one at the back (north-facing wall) and two on the side (east-facing wall). At first scale models did not include shading devices; later on shading devices were added. The removable ceiling plenum allowed testing different designs of light pipes [11, 12].

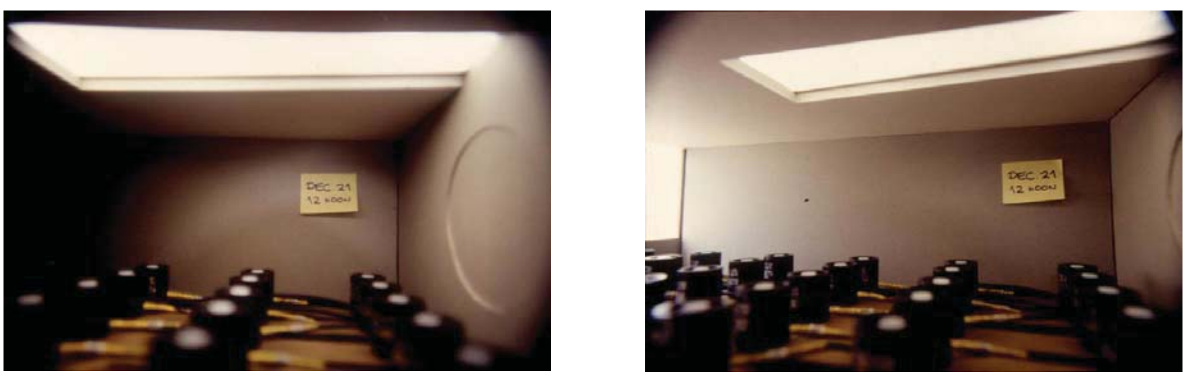

Fig. 1. Interior views of scale models with light pipe: without sidelight window (left), and with window (right).

Fig. 2. Two large scale models: test and reference models (left), and interior view of test model showing light pipe (right).

C. 75% of full scale

To predict more accurately the lighting and energy performance of our CFS, a larger experimental facility, was built at the Architecture Ranch Fabrication Facility at Texas A&M Riverside campus. It was built in an old shipping container which was adapted to represent a section of an office space with an unobstructed south view, at 75% of full-scale (Fig. 3). The room dimensions were 30 ft long, 20 ft wide, 10 ft high, 300 ft^2. The space included a sidelight window of 9.3 ft wide by 5.3 ft high with WWR of 41%, WFR of 16%, and glass with VT of 79%. The window is shaded by seven exterior horizontal louvers with a reflectance of 0.8 to block direct sunlight. The interior surface reflectances are 0.8 for the ceiling, 0.7 for the walls, 0.3 for the floor, and 0.5 for the desks. The original planned setup of the 75% of full-scale facility included electric lighting, lighting controls and an air-conditioning unit; however, due to power limitations at the test site, all these features were not tested.

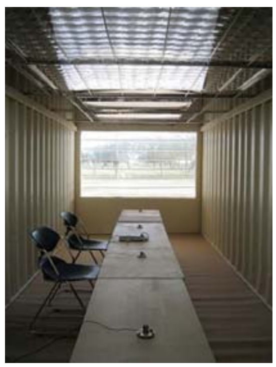

Fig. 3. Exterior and interior views of 75% full scale model.

D. Full-scale rotating room

Initially, two identical full-scale rotating rooms were planned to represent a reference and a test case (similar to the above large models 1:4). The testing required that the buildings rotate around an axis so that one does not cast shadows on the other, and both exposed to the same environmental conditions (sun angles, views, shading, etc.) during the whole year. Three construction systems (Stick frame, Rammed Earth and Structural Insulated Panel) and four methods of structure rotation (wheels on concrete slab, wheels on steel rails on concrete slab, floating on pressurized air, and floating on water) were also studied and compared (Fig. 4).

The construction system selected was the Structural Insulated Panel (SIP) due to it has higher insulation and light weight. The rotating system selected was the wheel-based system because of low cost and easy to operate. Due to site restrictions, only one room with two large windows (9 ft wide by 5 ft high) was built, which represents a workspace of 20 ft wide, 30 ft deep and 8 ft high with 3 ft high ceiling plenum. A removable partition along the center of the room will divide it in two spaces (RM and TM). Each space will have a window of 9 ft wide by 5 ft high and glass with VT 0.51, SHGC 0.22 and U-factor 0.27.

Four pivoting axel casters have been used to rotate the room. The diameter of the wheels is 10 inches, and the four casters can support 22,000 lbs. The rotating room will be equipped with external automated louvers, energy efficient electric lighting, DALI lighting controllers, packaged terminal air conditioning unit, and with a passive solar light pipe system. The room will rotate every 15˚ from True South simulating rooms with different façade orientations (Fig. 5). Energy consumption due to A/C and lighting will be collected to evaluate the performance of the integrated building systems.

DISCUSSION

Small scale models were extremely useful as a first proof of concept of our solar light pipe systems. Even though, small scale models are not accurate in assessing the lighting performance in interior spaces, they are helpful in providing feedback to make a first selection of alternate daylight systems. Due to the size of the model, we were able to have removable walls and roof to accommodate different alternate designs. Construction of our light pipe systems in a small scale had significant source of errors. Photography to observe daylight qualities was limited to few view angles.

In large scale models (i.e. scale 1:4) materials are represented with more accuracy. However, CFS with relatively small components that cannot be scaled down from full-scale presents source of errors. High Dynamic Range (HDR) photography and observations of daylight qualities was better documented at this model size. We were able to conduct surveys to a sample of 25 participants, who were able to observe and evaluate visual comfort from different view angles. These scale models need to be constructed with weather resistant materials for their long term exposure

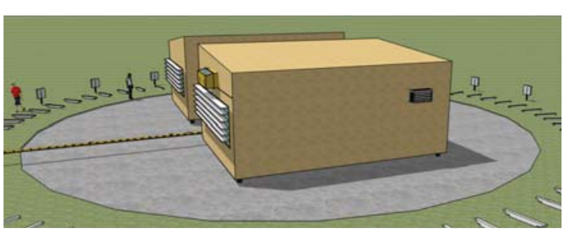

Fig. 4. Structures rotating on wheels (left), and on water (water).

Fig. 5. Exterior view of room (left), and sketch of room rotation every 15˚ (right).

to extreme weather conditions. Our models were monitored for about 4 years. It required periodic maintenance due to high speed winds and hot summer temperatures. Solar access of the model site was evaluated carefully, since our solar light pipe design needed a broader view to sunlight throughout the year to increase its lighting performance.

Models 75% of full-scale provided more accurate information. We were able to represent an office space with optical materials almost at full-scale. Since we used a shipping container, only half of the width of the room (10 ft) was represented. We built only the front and back façades of the room; this was an economical and relatively fast construction process. One drawback of using the container was that the metal structure transferred immediately the outdoor temperatures. Temperatures in College Station, Texas reach over 100˚F during summer months and 32˚F in winter months. This facility is being used for long-term monitoring of our light pipe for three years. We plan to continue using it for testing other design alternatives. A wide range of measurements have been conducted in this room of the light pipe luminous performance: illuminance over workplane recorded every minute throughout a year, spatial illuminance distribution of light pipe output, cubic illuminance, color temperature, HDR photography for creating luminance maps and glare metric tests. We found that the scale of the room is adequate for validating lighting computer models of our light pipe design [19, 20, and 21].

Our new full-scale rotating room offers the highest accuracy of all the other models. The room is a low-cost facility with a manual rotation of 360˚. The collected data in this room will serve to validate the lighting and energy performance of CFS in state-of-the-art simulation procedures. In addition to the data we had collected in the 75% of full-scale room, we will monitor the energy consumption of electric lighting and cooling loads over a wide range of façade's orientation. We will be able to conduct extensive surveys to assess the visual qualities of the space and study the probabilities of glare in high performance integrated systems. One limitation of the current full-scale room construction is that the windows are not removable; it will not be possible to test different types of glazings. However, small window sizes can be tested covering part of the total glass area.

The rotating room will allow us to conduct a comprehensive assessment of the lighting and energy performance of our light pipe design throughout a year for different latitudes and building orientations (Fig. 5). Fig. 6 depicts the multiple technologies interacting to achieve a low energy building. This rotating room will be a powerful educational tool for students and faculty, and will serve as a research facility for the scientific community to evaluate new advanced envelope lighting technologies and CFS. The room is almost complete at present time.

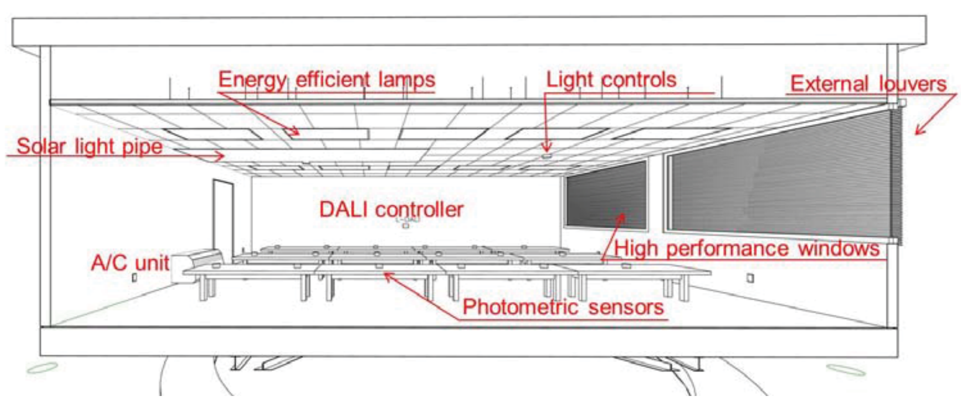

Fig. 6. Integrated technologies in experimental rotating room.

Conclusions

All systems were useful for each different design stage of our CFS prototype. Each tool provided useful information for the level of detail required by the scales of the models. We conclude that the two most useful tools to assess the effectiveness of our prototypes were the 75% of full-scale room, and full-scale rotating room. We aimed for low-cost experimental facilities that can serve as research tools, and as educational facilities to train future architects, lighting designers and engineers. The last two facilities serve as extensions of the classroom to provide a more practical understanding of lighting and its interactions with several building components. These facilities will become demonstration rooms of energy-efficient building technologies. Several undergraduate, masters and doctoral students from Architecture, Construction Science, Electrical and Civil Engineering participated in the construction of many of the room components.

Many new ideas have emerged during the construction of our last rotating facility. We have started planning our next testing facility. Our goal is to develop a rotating low-cost flexible facility with movable walls and roof to allow the testing of multiple sustainable envelope technologies.

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