Thermal Technological Dependence

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INTRODUCTION

The architecture of I.M. Pei is identified by a clear commitment to large expanses of glass supported by clearly visible and expressive structural frames. The large exterior transparent surfaces provide bountiful amounts of daylight and, as a function of orientation, opportunities for frequent solar glare and the capture of large amounts of radiant energy in the envelope interior. This architectural vocabulary is evident in the East Building of the National Gallery of Art (Washington DC, 1978), the John Fitzgerald Kennedy Memorial Library (Dorchester, Massachusetts, 1979), the Louvre Entry Pavilion (Paris, 1989), and now in the Rock and Roll Hall of Fame (Cleveland, Ohio, 1995).

This paper is a report of the investigations we have conducted to discover the impacts of the daylighting and solar energies upon the Rock and Roll Hall of Fame, and the users of that space.

A RELOCATED BUILDING DESIGN

The Rock and Roll Hall of Fame was originally designed to sit on another site in downtown Cleveland. The original site and corresponding design were located on the eastern edge of the banks of the Cuyahoga River, related to the city center or Public Square, and included a large northeast facing glass enclosed entry facade. When that site proved to be too tight for the amount of traffic and activity contemplated for the project, the site was changed and the original building design moved to the new site. This new site is on the edge of Lake Erie. Consequently reversing the building orientation and its relationship to the city center and skyline. What was previously a northeast entry facade defining an enclosed glass arrival atrium was rotated and became a southeast facing element and a space exposed to direct daily solar radiation. This rotation of glass facades stimulated questions for us concerning the impact of the solar energies upon the enclosed environment as generated by the changed orientation. It posed a unique opportunity to examine and address questions as to the influences of natural light and heat upon enclosed environments and the aspect of building orientation. Did the southeast orientation sufficiently increase the solar influence on the building interior to detract from or reduce the architectural quality or, perhaps, did it increase the quality, or were the influences inconsequential to the overall goals and intentions for the space and building? How important is the connection to nature for building occupants and how does an awareness of the daily and seasonal solar cycles influence our enjoyment and use of a space?

The building is composed of a seven-story, 167-foot-high, 60-foot-square tower backing to Lake Erie at the northwest. Attached is a sloping glass triangular tent facing roughly southeast and enclosing the central arrival and circulation area. This triangular space is approximately 292 feet long in plan facing southeast with two adjacent vertical glass walls, approximately 162 feet long, facing west and north. The long southeast facade is at a 45" slope to the north tower and the horizontal ground entry plane. Entry to this arrival space is over a paved exterior plaza that serves as a roof to the main exhibition area. This below-ground exhibition area contains the largest exhibit content in the building.

Pei's effort to capture the vibrant and rebellious nature of the rock and roll culture is expressed in various geometric volumes exploding from and through the tower and glass atrium. Visitors, upon arriving in the atrium, are led to the lower level via an escalator, to begin the museum tour in the large, underground exhibition space. Upon completion of this aspect of the tour, they are led to another escalator, which transports them up two levels, through the main entry floor level to the second floor level and then, via another escalator, to the third floor where a cafeteria is located. This cafeteria floats within the glass atrium on a horizontal plane extending out toward the glass roof. From this level, visitors proceed upward to and through the fourth and fifth levels and exhibits to the culmination of the trip on the sixth floor where, within the tall tower, is located the "Hall of Fame." The honorees are exhibited in a darkened room in an environment that is probably the most problematic space in the building due to its limited circulation area and lack of sufficient light for movement through the space. The circulation into and through the north tower is crowded and circuitous. The routes are forced

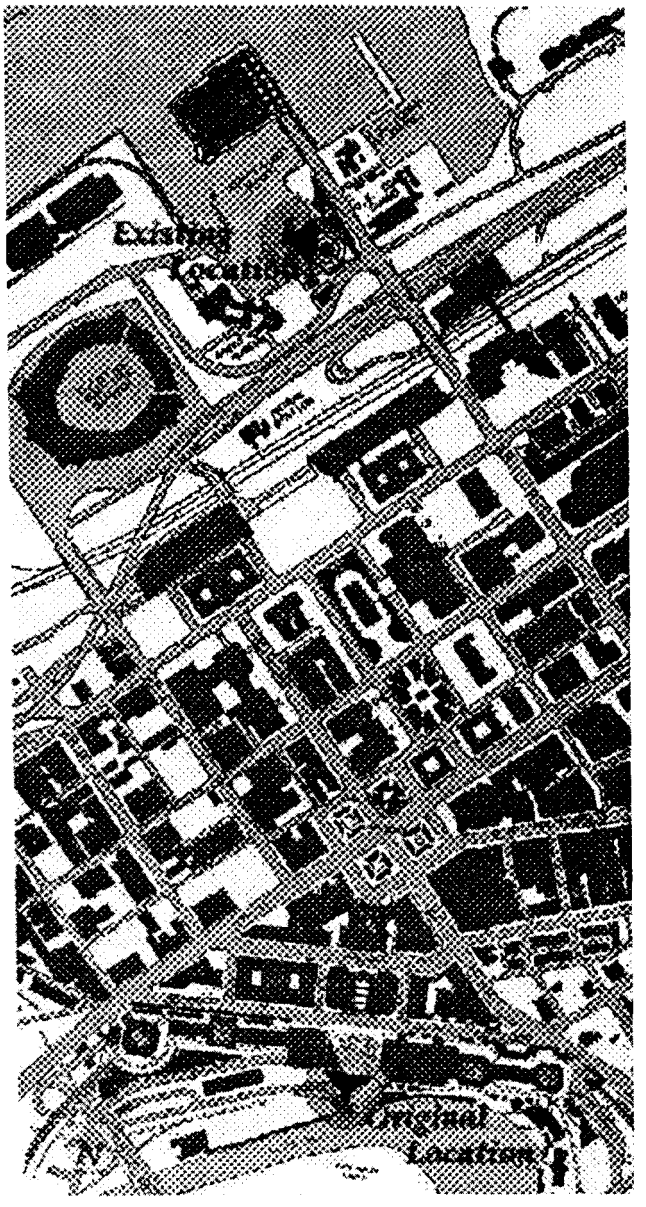

Figure 1. Existing and original site locations.

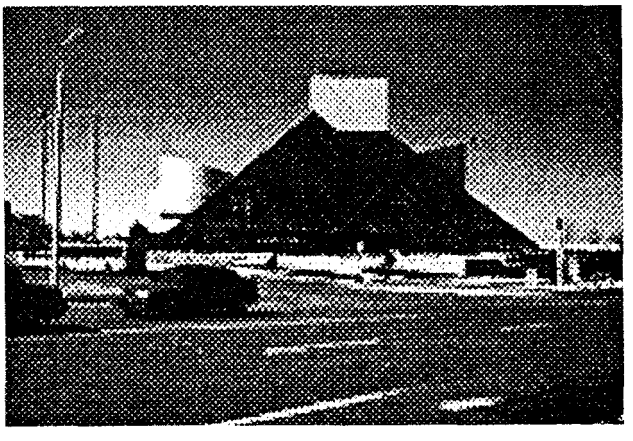

Figure 2. Southeast elevation.

and do not appear to have been given a great deal of planning.

The glass atrium has, however, proved to be an exciting focal point, not only for the visitors, but also for the city of Cleveland. The exterior image of this space and its relationships to the other forms have become the community symbol and icon. From the standpoint of an architectural, aesthetic experience, the space works very well. Visitors and employees, typically, overlook the building circulation, functional, and environmental problems, and are entranced by the cultural features and spatial excitement.

From the standpoint of standard human sensory and functional comfort criteria, the space is less than satisfactory. Comfort is achieved as a secondary issue relative to spatial and cultural experience — then at a considerable cost in material and energy resources and financial expenditures. It is this space upon which we have focused our attention in measuring the environmental performance. We have sought to better understand the role of environmental sensory experience and systems in achieving a significant architectural monument.

BACKGROUND STUDIES

Under a "Vital Signs" grant, we have conducted a study of the atrium environment and the building performance. This study involved a careful analysis of the impacts of solar energy upon the space and its occupants. We examined the thermal and visual conditions provided the occupants at critical points within the space. The daylighting was measured and evaluated throughout by on-site measurements, physical models, and "Lightscape" computer models. An analysis of the annual energy consumption was conducted through the use of the "Ener-Win" computer simulation program, authored by Professor Larry Degelman, Department of Architecture, Texas A&M University.

The results of this study are documented in a report under the "Vital Signs" project by the University of California. This project can be visited at: http://WWW.saed.kent.edu/~kremers/rock.html

VISUAL ENVIRONMENT ANALYSIS

We learned through this study that excess visual contrast levels do exist in the space during many daylight hours, particularly in mid-morning clear weather conditions. The contrasts are not constant and have a very dynamic quality. The wall structural elements create continually shifting shadow patterns on the floor and interior walls as they intercept and absorb a portion of the incoming solar energy.

Prior to the opening of the facility in the Fall of 1995, Mojtaba Navvab, Professor of Architecture at the University of Michigan, conducted an investigation of the visual glare problems posed by the southeast glass facade. His report is in the February 1996 issue of *Lighting Design and Application* and the Summer 1997 *Journal of the Illuminating Engineering Society*. Navvab's investigation identified the existence of significant glare within the space.

The daylighting analysis, conducted by the University

of Michigan Daylight Simulation Laboratory, considered the complexities of daylighting. The study included the shading coefficient of the glazing system; glass transmission; luminance and illuminance measurements, both on-site and computer correlates; and the impact of direct, reflected and contrast glare at various times of the day. The investigation identified problem areas near the apex of the atrium, the entry on the first floor and the balcony above the video wall."

Navvab measured average horizontal illuminances reaching 3000 fc. He comments:

hourly conditions could generate 6000 fc or more with internal inter-reflection. At the three problem locations, the average CIE glare rating under clear skies varies from 60-75, placing it in the 'disturbing range.'

Through our model studies and on-site measurements, we verified Navvab's data. Daylight measurements varied from 60-4600 horizontal fc in our studies. The data is elusive. The shadow patterns and moving direct solar light source make it difficult and, arguably, irrelevant to establish fixed and comparable illuminance and luminance values.

Glare and excess contrast levels exist relative to the various visual functions and tasks. We identified six critical visual tasks:

(1) The task which initially stimulated Navvab's work was motivated by the potential solar radiation damage to the commercial displays. The potential is real, much like that in a museum or library, where radiation will always do irreparable damage to the artifacts and storedmaterials. In the store-like atmosphere the employees and shoppers, blinded by direct sun, generally overlook the excess contrast. The possibility of reduced sales in the spaces due to customers avoiding the environment under high contrast conditions is a question for the retailers to address.

(2) A second visual task, closely associated with the retail spaces, is the observation of video monitors located above the sales displays. The monitors display rock and roll performances. These TV displays are virtually unnoticed, not only as to the programmed contents, but even as to their very existence. Building users fail to observe these elements because the daylighting drowns out and eliminates the contrasting visual signals provided by the monitors.

(3) At the cafeteria level, the visual tasks associated with dining, including a heads-down view of the table tops and a heads-up view for conversation, are very difficult to tolerate on clear days. The surrounding vertical surface contrasts overpower the desired visual goals. The interior vertical white surfaces as well as the dominating views to the exterior are excessively bright and cause contrast levels which produce visual glare and discomfort. Also, the solar radiation thermal heat absorbed by occupants of the space produces uncomfortably warm conditions not measured by the HVAC control systems. The combination of the visual glare and the high temperature conditions causes people to move to other locations. This location is one of the most dynamic and exciting locations spatially, but the more confined dining areas receive the greater use. One of the human dynamics is that in a large volume such as this, people simply move to another location when they experience sensory discomfort and still find themselves within the total spatial experience.

(4) Another extreme occurs at the main entry level, where the south facing store is separated from a rear store area by a storage and elevator enclosure. The rear or north store area is lighted at much lower levels than the front or south area. This north area is open on the west side to the atrium and the views into the store from the atrium provide contrast levels that make it nearly impossible to ascertain the visual detail in the store.

(5) Circulation lighting relative to the visual task is adequate until reaching the pinnacle at the "Hall of Fame." There is more-than-ample light throughout the central atrium space for circulation. When the enclosed, totally electrically lighted "Hall of Fame" exhibit is entered, the lighting levels suddenly become extremely low and a period of time is needed to adapt to the reduced levels.

(6) Other exhibit spaces are electrically lighted to adequate levels and the design of the exhibit lighting is typically high contrast and focused. Daylighting is not available in most of the exhibits.

In contradiction to our original thesis that the orientation of the building was the reason for excess visual glare occurring in the atrium, we learned that rotating the atrium in any direction did not appreciably eliminate the problem of visual glare. The triangular plan of the atrium is defined by not only the sloping glass entry wall but also by two triangular side glass walls. Only the vertical rear tower is an opaque enclosure element. Rotating the atrium simply exposes another glass facade to the problem causing solar conditions.

THERMAL ENVIRONMENTAL ANALYSIS

We also investigated the thermal conditions within the atrium. We were particularly interested in the question as to whether the large amounts of solar energy that entered the space on clear days would create conditions that provided excess heat or conditions too warm for thermal comfort. The original project was conducted during the spring of 1996. While the solar impacts were significant, the warm exterior temperature and high humidity conditions of the Cleveland summers did not occur during this time period. It was not until the summer of 1996, when wedidin-depthoccupant surveys, that we were able to correlate the hottest periods of the year with our data.

Solar radiation does cause local discomfort as indicated in the previous discussion concerning the cafeteria lighted environment. At the time of this article, with admittedly limited data, we find no correlation between warm exterior air temperature conditions (as distinguished from solar radiation heat gain) and indoor thermal discomfort. Thermal discomfort due to large amounts of interior heat gain does occur but it is due to the HVAC distribution system. The mechanical systems overpower the excessive cooling loads. This satisfies the temperature conditions at the control points. It also leads to one of the thermal problems identified in the study.

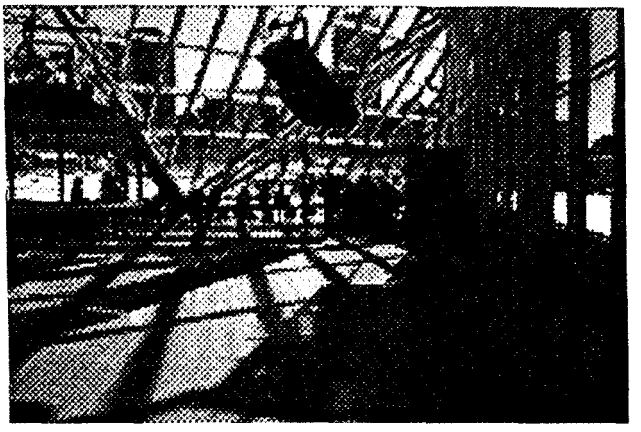

Figure 3. Interior visual contrast.

We heard very soon in our studies that people complain about cool drafts from air supply delivery devices located at the ground floor or main level of the atrium. The large amounts of air required to cool the space are introduced at occupant level around the glass perimeter. Occupants who get close to these air supplies experience temperatures too cool and drafts too high in velocity for comfort within the supply air paths.

Another problem is that the 115 foot high vertical open space of the atrium provides great opportunity for stack effect heat to collect at the upper levels. The cafeteria, escalators, balconies, and a number of exhibits are open to the atrium, separated by vertical position. The large air handling systems cannot provide uniform thermal conditions within this space. Cool conditions at the main level do not eliminate typically warm conditions at the upper levels. The building service director has addressed this problem by opening the fire exhaust grill at the top of the atrium on warm days so as to pull the cooler supply air to the top of the atrium and exhaust the warmer air completely to the outside.

Temperature measurements at the main floor bookstore and at the third floor cafeteria illustrate the differences. The comfort zone of 68-72" is exceeded frequently at the higher interior levels. Temperature sensing devices were exposed to the solar radiation as well as the air temperature. They express not only the ambient air conditions, but also the differences due to solar radiation on clear days as opposed to cloudy days. The temperature differences approximate 1 0 F higher temperatures at the third floor as compared to the first floor.

VISITOR SURVEY

A questionnaire was developed to determine visitor response to the environmental issues and their perception of the lighting and thermal environments and systems. This questionnaire was administered during the summer of 1996.

Three locations were chosen for students to administer the questionnaire to visitors occupying those locations. The three areas were the main floor entry, the book and gift shop on the main floor, and the third floor cafeteria. These three areas had proved to be significant in our measurement studies as clear indicators of thermal and visual influences due to the building envelope and orientation. Additionally, they were areas that typically required visitors to remain a significant amount of time in order to experience the functions associated with the locations; thus they would experience the environmental issues with which we were concerned. Documentation of the length of time a typical visitor remained in these locations varied from fifteen minutes to over one hour.

Questionnaires were distributed between the hours of 10:00 AM and 3:00 PM on the hour on randomly chosen mid-week days during the months of June, July, and August, 1996. Corresponding exterior temperature data was collected from the National Weather Bureau. The building service director verified the thermostat settings as being constantly between 68°F and 72°F at the times the questionnaires were administered.

PERCEIVED THERMAL COMFORT

The HVAC system includes more than 280 thermostats generally set to maintain the measured temperatures within 2 ° +/- of 70°F. During the summer months this temperature is set regardless of what the exterior temperature conditions are.

Table One indicates the "visitors' perceived temperatures" associated with these conditions. The indoor temperatures are constant as explained above. The outdoor hourly temperatures are the total ranges documented during the all of the questionnaire times.

Perception of the indoor temperatures varied from 13 ° below the set temperature to 18 ° above the set temperature. In spite of these significant perceived temperature ranges and their difference from the normal comfort zone (68"-78 °), 78% of the respondents indicated they were comfortable. Significantly, 22 %expressed the feeling that they were not comfortable or satisfied with the interior temperatures. Of this 22%, 72 % found the space too cold and 28% described the space as too warm. In relation to location, the bookstore were perceived to be below the thermostatic setting by 73% of the respondents. The entry location was perceived to be below the thermostatic setting by 68% of the respondents. By contrast, 92% of those interviewed expressed the perception that the cafeteria was above the thermostatic setting.

TIME (DST)	OUTDOOR TEMPERATURE RANGE (F)	PERCEIVED TEMPERATURE (F)
10 AM	68 -78	60 -85
11 AM	68 - 82	50 - 85
NOON	72 - 82	74 - 89
1 PM	72 - 82	50 - 85
2 PM	72 - 83	40 - 90
3 PM	73 - 83	55 - 82

Fig 4. Table 1.

PERCEIVED VISUAL COMFORT

Many visitors to the building will enter wearing sunglasses or tinted lenses and continue to use those shading devices in the interior. The light levels are such as to generate the impression of exterior lighting quantity. It was decided to document the number of visitors who continued to wear shading devices in the interior. This number proved to be 18% of those interviewed. Additionally, of those not wearing shading devices, an additional 13% expressed some visual discomfort. Typical answers as to why and where this discomfort arose were excess overall light quantities and glare.

CONCLUSIONS

The building could be better. It could be a great piece of architecture. A strong visual expression has been created and an inviting space in which to display and store the artifacts of the cultural phenomena, "Rock and Roll," stands along the shores of Lake Erie. Within this sculptural enclosure a satisfactory environment for human occupation, comfort, and performance exists. It is not an optimal environmental condition based upon current environmental standards and the opinions of a number of building occupants. In addition, the satisfactory environment is maintained at a considerable cost in materials, operating energies, and financial expenditures. If the design process had included consideration of climatic responsive elements, the ultimate project would not only have been greatly enhanced, but the opportunity to create truly significant architecture would have been grasped.

Solar shading devices at the glass envelope, either on the exterior or the interior, would have eliminated the problems of visual glare and extreme contrast, radiation damage to the book and gift shop artifacts, and excess interior solar heat gain. The addition of these elements to the original building form does not appear to be a detracting consideration. The addition of these elements after completion of construction is a costly endeavor wrought with the difficulties of detailed integration with the existing envelope elements.

The inclusion of a natural stack effect ventilation system would be a natural consequence of the overall building form and interior space concept if it were considered in the design process. The building service director has intuitively grasped this concept in the use of the fire and smoke ventilation exhaust system for peak cooling load conditions.

Recognition of the local interior thermal conditions created by HVAC distribution system in the design process would have provided a more uniform and integrated interior thermal environment. Supply outlets located with respect to the occupants and sensitivity to the thermal paths to the return air grills would provide increased human comfort and not just adequate balance for the total space with respect to the exterior environmental conditions. The resulting enhancement would produce increased use of the truly exciting spatial experiences and decrease the demand for energy resources to provide conditions of thermal comfort in extreme situations.

These are the decisions that must be integrated in the design process from the earliest stages. They cannot be added after the "concept" is defined. These are the kinds of decisions that we must integrate within the architectural design educational process. Only then will future "Rock and Roll Halls of Fame" become significant architecture.

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