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ATRIUM DESIGN CRITERIA RESULTING FROM COMPARATIVE STUDIES OF ATRIUMS WITH DIFFERENT ORIENTATION AND COMPLEX INTERFACING OF ENVIRONMENTAL SYSTEMS

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ABSTRACT

Atriums have become successful solutions in commercial and institutional buildings when large spaces are provided for various purposes in multistory buildings. They are often enveloped with large glass wall and roof areas that provide ample daylighting but also result in complex interfacing of heating, cooling, and ventilating, the stratification of air, and problems with indoor air quality, acoustics, and control of the environmental systems.

Research of this interfacing is difficult to perform as simultaneous observations and continuous diurnal and seasonal data recordings are needed in order to better understand how the various systems and conditions interact. The analysis of observations and collected data is also a difficult task, as design conditions vary, the orientation of atriums differs, and environmental systems are often designed with inadequate understanding of the complexity of this interfacing.

This author has observed various kinds of atriums for a long time and conducted organized research in several atriums for the past six years. On the basis of these observations and results of the research, relevant design criteria are offered for orientation, the building envelope, HVAC systems, avoidance of stratification of air, indoor air quality, acoustics, and general considerations of design, especially regarding the use of an atrium as a return air plenum and for its function as part of the total building performance and relation to surrounding spaces.

INTRODUCTION

In commercial buildings, atriums may serve a wide variety of functions. For example, enormously large shopping centers with enclosed atriums have replaced Main Street and combined the functions of retail and department stores, restaurants, and entertainment in a multilevel and multipurpose space that attracts large numbers of people and pulses with life from early morning to late at night. Civic centers and convention halls are "natural" as users of atriums for large exhibit spaces and masses of visitors. Hotels also cater for conventions and offer conference centers, often combined with multistory atriums with escalator access to conference floors and commercial spaces. Transportation terminals, sports complexes, and industrial and office buildings provide atrium spaces for various functions. While energy conservation may dictate some design criteria, other considerations, such as profitability, productivity, and convenience, often dominate the decision-making process.

In institutional buildings such as schools, hospitals, and laboratories, decision making may be based on a longer time view and wider range of considerations for occupant health, safety, and welfare. Selection of site, building orientation, building materials, and environmental systems can often be made with more concern for energy conservation, proper utilization of solar energy and daylighting, better acoustics and controls for the benefit of both occupants and the general public. Results of relevant research can be more easily incorporated in the design, and monitoring of building performance becomes a somewhat easier task in the more secure circumstances.

The research on which this paper's recommendations of design criteria are based has been conducted in several university buildings, four of which have been selected as examples because of their differing orientations (north-south, east-west, southeast, and southwest-northeast exposures), their similar environmental systems and controls, and research results based on daily and seasonal data.

RESEARCH ON FOUR BUILDING ATRIUMS

Of the four buildings selected as examples, one has an east-west, three-story atrium used primarily as a lobby and light well area, open to adjacent corridors and offices with doors that are usually closed. It is a communications center

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with a number of rooms containing extensive computer equipment. The second building, a molecular biology laboratory, has a north-south atrium that is almost entirely separated from adjacent building spaces but serves as an excellent light well for four stories of laboratories with windows to the atrium. The third is a library building with a four-story atrium oriented to the southeast and open to adjacent spaces that include book stacks and public areas on each floor. The fourth is a college building with a five-story atrium orientated from southwest to northeast, open to adjacent corridors, offices, and studios, with doors usually open (in violation of principles of fire séparation and of energy conservation considerations).

Organized research has been conducted on theses building atriums at different periods. The college building provides measured data for six years, the library and communications building for one year (simultaneously with the college), and the molecular biology laboratory for one season. Measurements have been taken at least three times a day, on the same day(s) of the week, through the seasons, of temperature, humidity, air movement, and light levels at various predetermined locations on each floor and of acoustics and indoor air quality at selected times and locations. Light levels have been taken for both daylighting and artificial lighting, at worktable levels and on vertical surfaces, and for reflectivity. The acoustical studies concentrated on reverberation, sound levels, resonance, and interference of sounds in the atrium. Additional observations were made of direct solar radiation effects on occupant comfort and use of spaces, effects of glare and visibility of exhibits on vertical surfaces, and use of the atrium for class and lecturing purposes, entertainment, study, relaxation, smoking, and even sleeping. For indoor air quality in the college atrium, a workstation was set up with a lockable data recorder/analyzer.

All four buildings receive their heating and cooling from a central district heating and cooling plant. Two of the atriums are used as return air plenums. Smoking is limited to designated areas and faculty offices in the college building and is not allowed in the other three buildings. The use of cleaning fluids and methods is similar in the four atriums. The college and library atriums are carpeted. The other two have terrazzo and tile floors. The vertical windows are generally of clear glass, but skylights and roof glass are of tinted, glare-reducing glass. The elevators open to the atriums. The district heating and cooling system provides opportunities for system-wide conservation of energy, but the interfacing of solar and daylighting creates both control and energy management problems, in some cases magnified by occupant ignorance, carelessness, and misuse of environmental controls.

EFFECTS OF BUILDING ORIENTATION

A fundamental aspect of atrium design is orientation to the sun and its effect on building use and occupant comfort. Depending on the orientation, the atrium receives direct sunlight in hugely different amounts from different directions during the day and the season. The "noon" in an atrium opening to a southerly direction occurs at a certain time, varying only by an hour because of daylight saving time. Depending on the sun angle and direction, the walls and the floor of the atrium are exposed to direct sun radiation for varying amounts of time and intensity. On cloudy days, dark and bright times will alternate, sometimes vary rapidly, and on overcast days, sky luminosity provides a more steady and uniform daylighting condition. The wide range of sometimes rapid changes in the amount of solar radiation results in one of the most serious control problems for HVAC systems, which can only be mitigated by use of various external or internal louvers, filters, and shades, combined with an appropriate selection of glare-reducing glass. The orientation of the atrium should be carefully selected with regard to the intended use of the building and its varying daily and seasonal functions.

LIGHTING AND DAYLIGHTING

After the orientation, conditions affecting lighting and daylighting must be seriously considered. The interior of the atrium has a wide range of light levels resulting from the variability of daylighting and the location of the areas within the atrium. To some extent, this variability can be mitigated by proper location and capacity of light fixtures and appropriate reflectivity of the wall and floor surfaces. For general lighting, this is not overly important, as long as minimum levels are ensured and the maximum levels are acceptable. For specific uses, task lighting should be provided. For high and "deep" atriums with only skylight available, daylighting can be directed down to the lower levels by the use of solar mirrors and Fresnel lenses. In atriums with adjacent eastern, southern, and western glass wall exposures, the use of operable louvers and shades may be considered. Care must be taken to design specific-use areas that avoid direct sun radiation.

STRATIFICATION OF AIR

Before the HVAC systems are designed, consideration has to be given to the shape of the atrium and the possibility of stratification of air. The "loft" space above the highest occupied floor must be adequate for containing enough air to reduce the stratification problem during peak periods of high temperatures, and/or adequate ventilation of that space must be provided either by forced recirculation or exhausting. Openable windows provide one solution as long as the occupants use them in accordance with the planned operation, but that is not usually possible. The use of night cooling by buildings masses is helpful, especially when it can postpone the peak period beyond the main occupancy period of the day. Forced recirculation may increase the cooling load, while exhausting from the loft must be combined with appropriate controls. Forced recirculation may also be difficult to accomplish or be impracticable because of the sizes and locations of adequate duct work involved.

HVAC SYSTEMS AND CONTROLS

Variable-air-volume systems work best in buildings in which the atrium is not used as a return air plenum. Demands for simultaneous heating and cooling at different locations within the building complicate the HVAC system design. The large volumes of air involved in multistory atriums are difficult to move and control, especially with the interfacing of solar power and daylighting. Energy storage systems such as ice storage can be used to reduce peak demands. Consideration should be given for district heating, cogeneration, and total building energy systems. In high-rise buildings, the locations(s) of the HVAC/power centers should also be considered in the vertical dimensions. Central vs. distributed systems may be considered. Where different tenants with different energy demands are located adjacent to the atrium, distributed systems may prove most practicable. In all cases, an understanding of the complex interfacing of the total atrium and building performance is necessary. The complexity is particularly intensive in an atrium that is being used as a return air plenum. The recirculation of the air from the adjacent spaces becomes a major problem. Fire regulations require adequate exhaust ventilation that is dependable without fail in case of a fire. Controlled exhaust to reduce peak cooling loads is also important when practicable. Equalizing temperatures in a multistory atrium is very difficult, and some atriums that have been studied have as much as 10-degree rises of temperature from the first to the highest floors. The mixing of the return air from various sources in the atrium also creates indoor air quality problems.

INDOOR AIR QUALITY

The quality of indoor air in an atrium depends on several factors: the sources, quantities, and concentration of pollutants and their proximity to the occupants. The smoking of cigarettes has been a serious indoor air problem. In an atrium, people odors, street dust, and emissions from copy machines and cleaning fluids are a problem, together with pollen and various other particulates.

CO and CO_2 concentrations can be studied, but it must be done systematically on a 24-hour and seasonal basis. The amounts of CO and CO_2 can vary tremendously, especially if smoking is allowed in the atrium or in the adjacent spaces from which return air is mixed in the atrium. Radon is seldom a problem. Noxious gases and harmful particulates are more difficult to study, partly because of the high cost of appropriate equipment and partly because of the quick contamination of particulate-collecting equipment. It is also often difficult to secure the research equipment against theft and vandalism. There are several solutions that may be considered for improving indoor air quality. The reduction of sources is important, and some sources can be isolated to their separate HVAC systems, as is done in laboratory buildings. Reduction in amounts may be accomplished by appropriate filtering and removal of odors and particulates near their sources. Reduction in the amounts from the exterior (pollen and dust) can be accomplished by control of entrances by revolving doors and vestibules. The ventilation of specific-use areas can be intensified locally.

In commercial atriums that include food production and eating areas, problems of indoor air quality and sanitation are multiplied. Pleasant odors, such as of fresh breads or favored foods, are mixed with emissions from charcoal grilles and garbage. People odors abound when masses of people mill around. Again, the first reduction effort needs to be near the source and the second should be proper ventilation in areas of people concentration. It is not easy to accomplish.

ACOUSTICAL CONSIDERATIONS

Acoustics is often ignored as a design criterion for an atrium. Noise levels must be, however, considered. Reverberation can be reduced by selection and placement of appropriate building materials and the shape of the space. Sources of noise at various sound frequencies need to be identified. Acoustical studies at the college atrium indicated that while the main problem was the reverberation of noise at various kHz frequencies due to lack of proper absorption, the levels and reverberation times varied because the locations of the sources moved through the atrium. An atrium does not act like a concert hall with a stage and audience. It is constantly changing, and the noise sources also vary. At the college atrium, sounds of spoken words may be muffled by the background noise or be absorbed too much in the building materials. Also, the space is used for a wide range of activities, such as study, lecturing, quiet relaxation, and noon-time band concerts with 80 dB or higher noise levels. A student's boombox in the fifth floor studio can interfere with the dean speaking to a parent group on the first floor. The same is true with most of the multi-use atriums, including those in shopping centers. The sources of particular sound frequencies and noise levels can be either isolated or more or less permanently located at certain preplanned areas. Sound travels in a spherical fashion, which is important to apply to conditions in a large atrium. The separation of the adjacent spaces by appropriate sound transmission coefficient materials is also important. To prevent resonance, double windows with two differing glass thicknesses are advisable.

ATRIUM RESEARCH

Because of the complexity of interfacing systems in an atrium, simultaneous research of the various elements needs to be performed in order to establish the cause-and-effect phenomena. When a solar outburst affects the heating and cooling systems simultaneously, causing ventilation effects, stratification of air, and air movement and humidity, all of which affect the occupants at various locations and levels, any independent system alone does not provide an answer. Because of that and the diurnal and seasonal effects involved, continuous measurements and data collection are needed by sensors at various locations within an atrium, simultaneously and for appropriate periods of time. Hand-held equipment, while useful and economical, is not enough; "work stations" with appropriate sensors and data-recording equipment must be used. This is expensive, and the equipment needs to be secured against theft and vandalism, properly calibrated, and systematically scheduled and observed.

CONCLUSIONS

The complexity of the interfacing of the various systems in an atrium must be reflected in the design criteria. Architecturally, the orientation, shape, and size of an atrium must meet the requirements of its purpose and use. Consideration must be given to energy conservation, appropriate use of materials for the building envelope, acoustics, and interior finishes and colors for reflectivity of daylighting. Various systems of louvers, shades, glare-reducing glass, and filters should be used to control direct sun radiation. The location of HVAC and power centers needs to be considered, particularly in high-rise atriums. Building masses should be used for purposes of energy storage.

It is even more important to understand the complexity for engineering of the environmental systems. The sizing and performance of the HVAC systems depend on the adequate design and control of the interfacing functions and system performances. Because of the large volumes of air and possible stratification, adequate ventilation and exhaust systems need to be properly designed. For the best indoor air quality, sources of pollution need to be reduced and isolated, when possible, and separate systems designed at the locations of sources of noxious gases and particulates to remove them from the atrium. If the atrium is used as a return air plenum, cigarette smoking must be either properly controlled or eliminated. Environmentally acceptable cleaning fluids should be used and their storage isolated.

The appendix shows research results and descriptions of the four example buildings in tables, diagrams, and pictures.

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Figure 1 *Midsummer "noon" at the college atrium.*

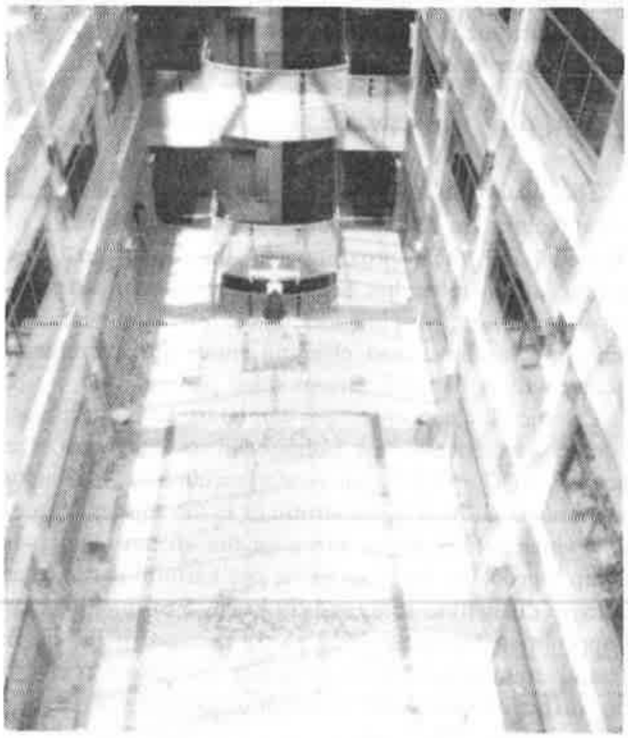


Figure 2 *Atrium of the communications center.*

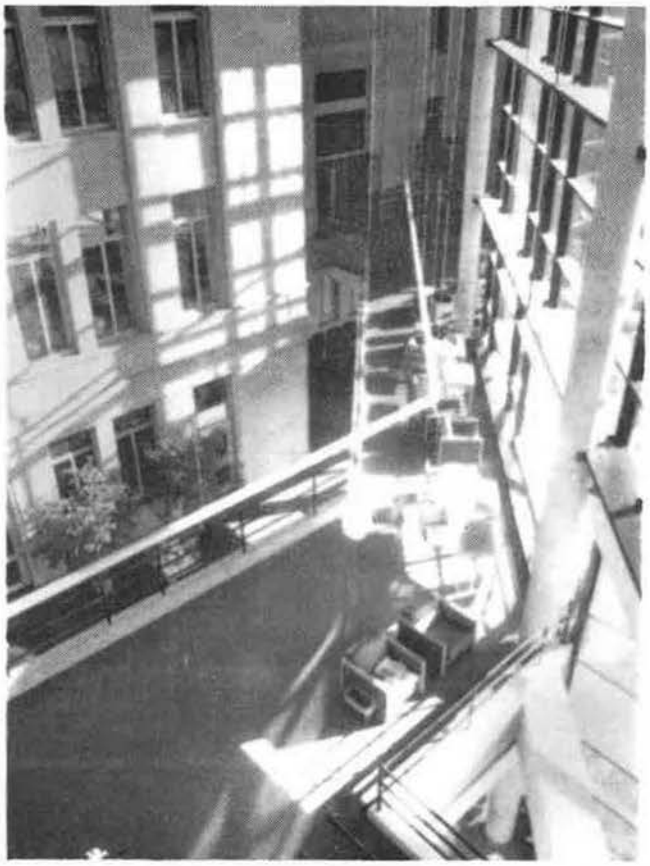


Figure 3 Library atrium seen from the upper (third) floor level.

Figure 4 Library atrium seen from the main (second) floor level.

Figure 5 Molecular biology building atrium.

Figure 6 Midsummer "noon" in the atrium.

LOCATION	TEMPERATURE °F	HUMIDITY %RH	AIRSPEED ft/min	LIGHT METER footcandles	PHOTOS f-stop 8 shutter 8
OUTSIDE:					
W					
E					
INSIDE:					
LOBBY					
1NE END					
1NE CENTER					
1SW END					
1SW CENTER					
STAIRS:					
2					
3					
4					
4½					
5					
5NE END					
5SW END					

Figure 7 *Data collection sheet.*

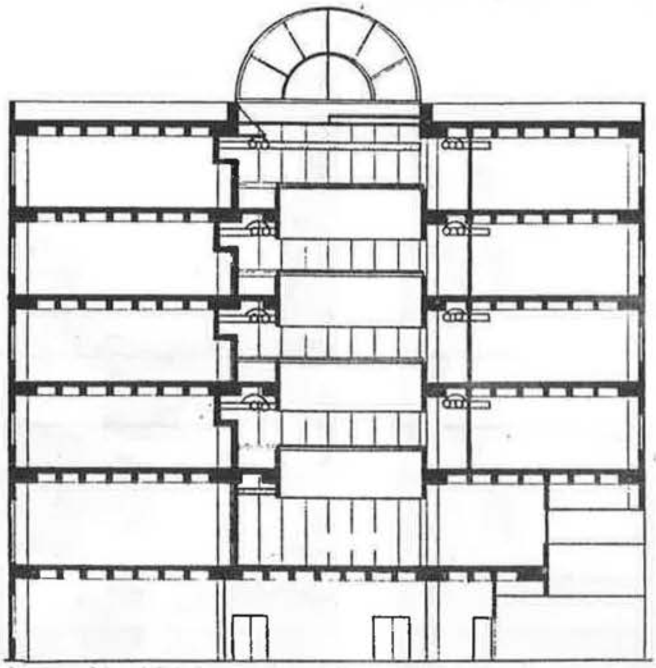


Figure 8 *Cross section of college of design atrium.*

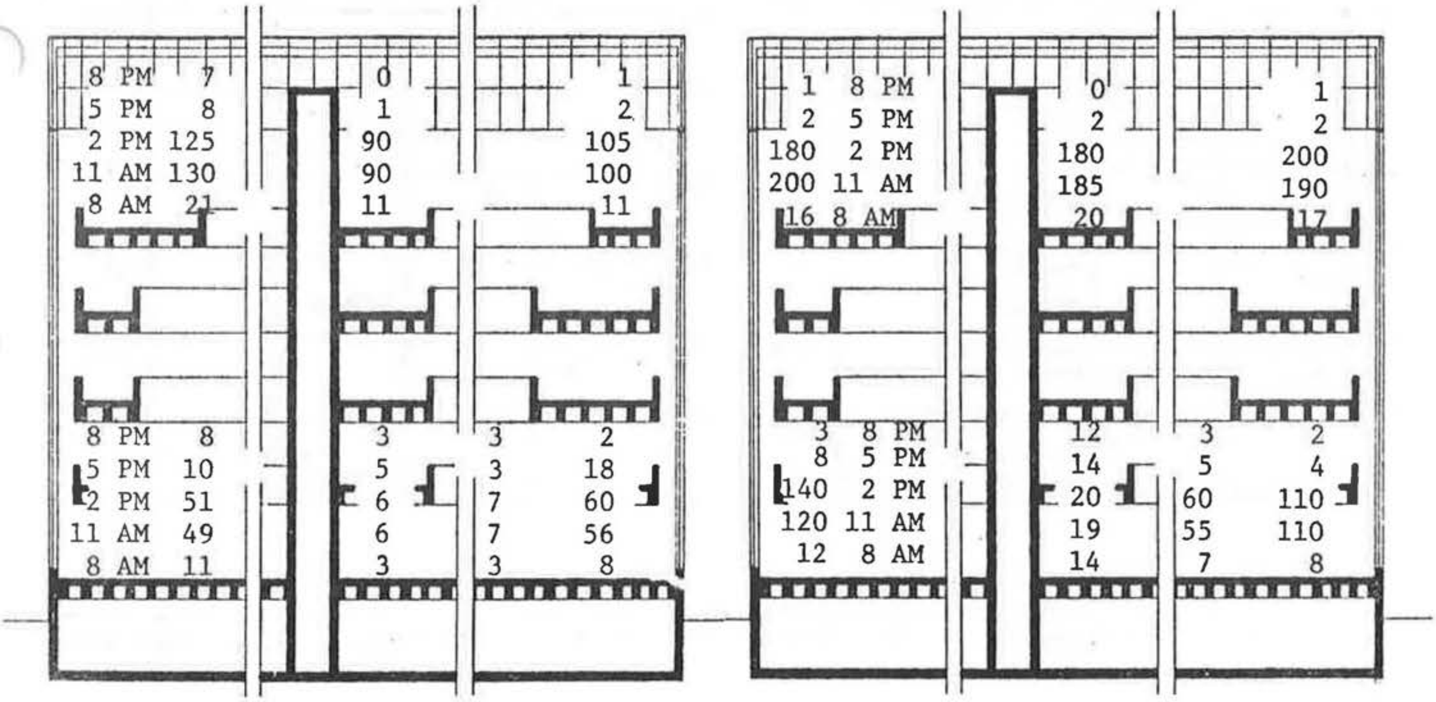


Figure 9 *Light level readings in the college atrium.*

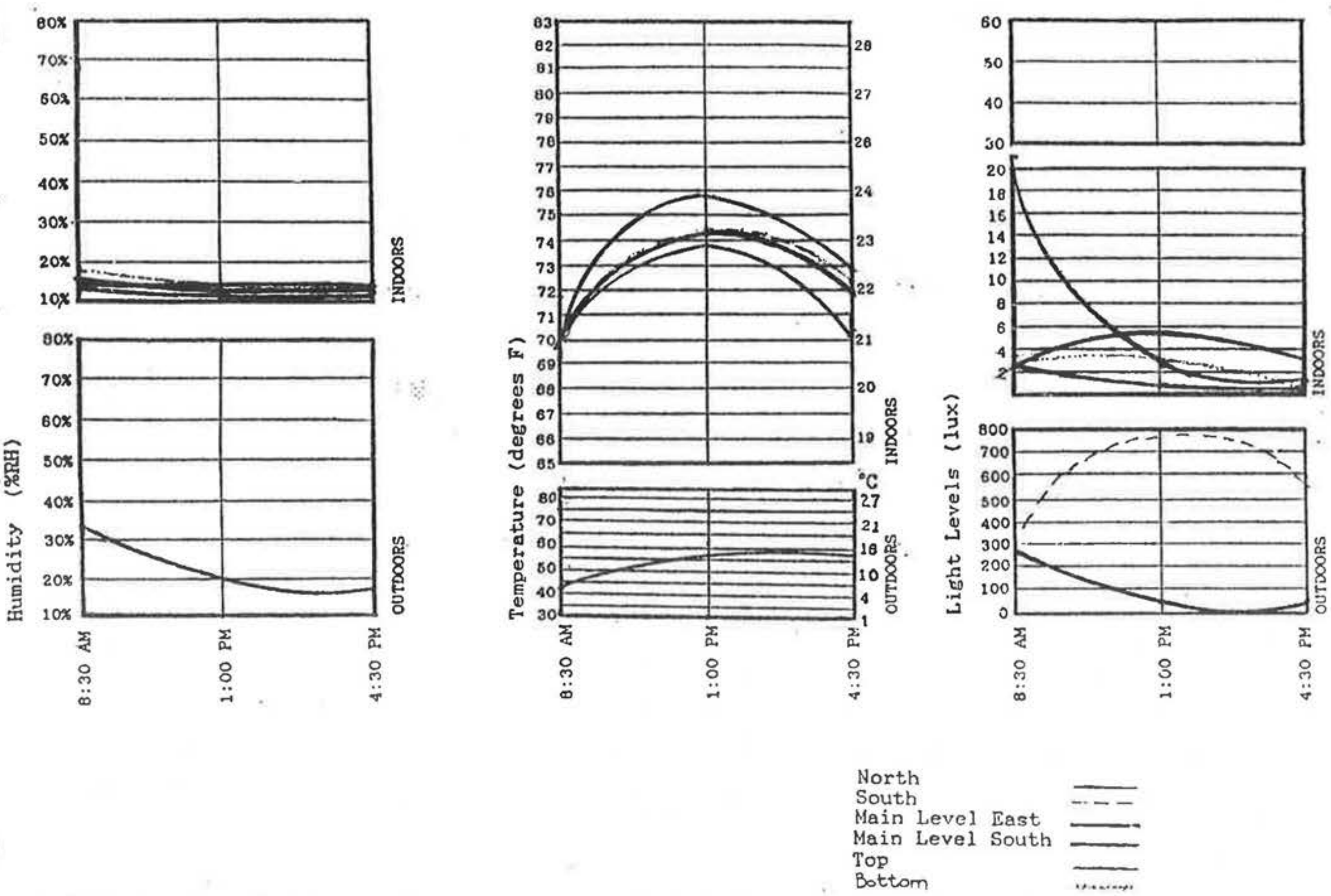


Figure 10 *Sample graphs of atrium data analysis.*

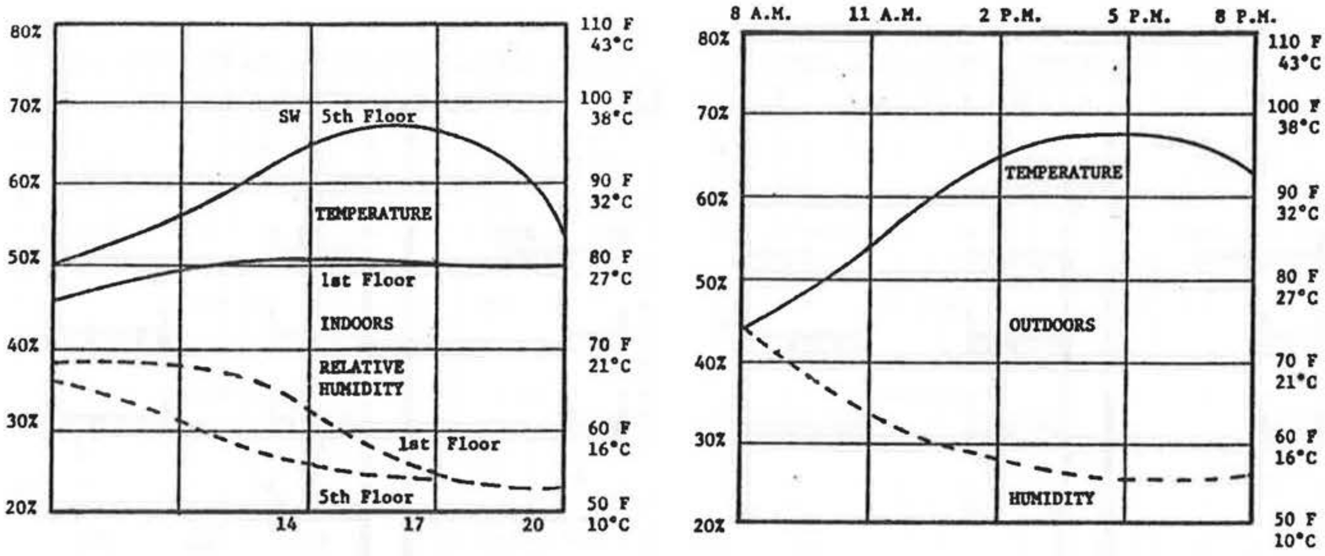


Figure 11 *Humidity. Relative humidity measured on a hot day outdoors and inside atrium, related to temperatures which are recorded at the southwest end of the fifth floor, but at the middle of the first floor in order to illustrate the maximum variations during the day. The top floor temperatures and humidity figures become close to those recorded outdoors.*

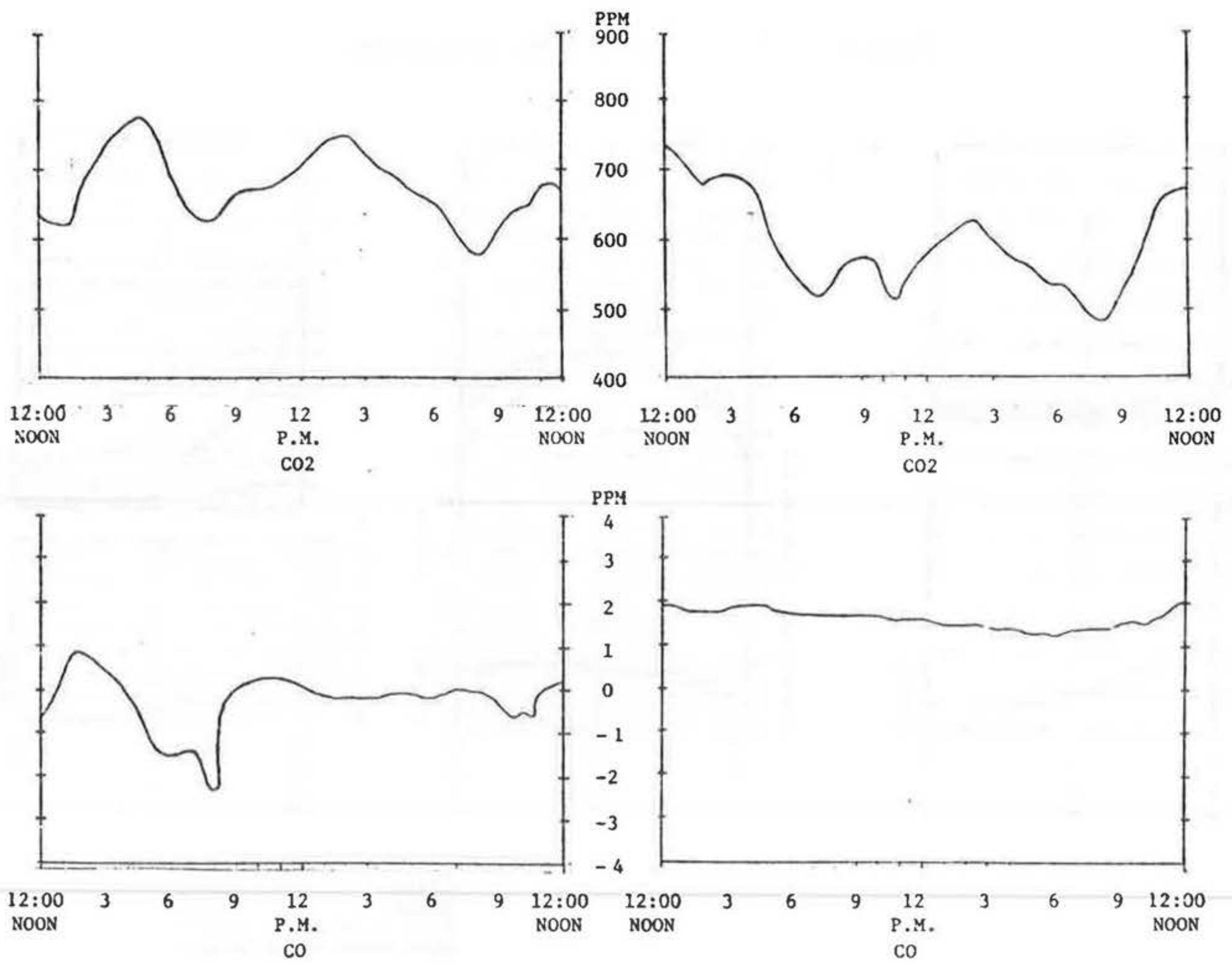
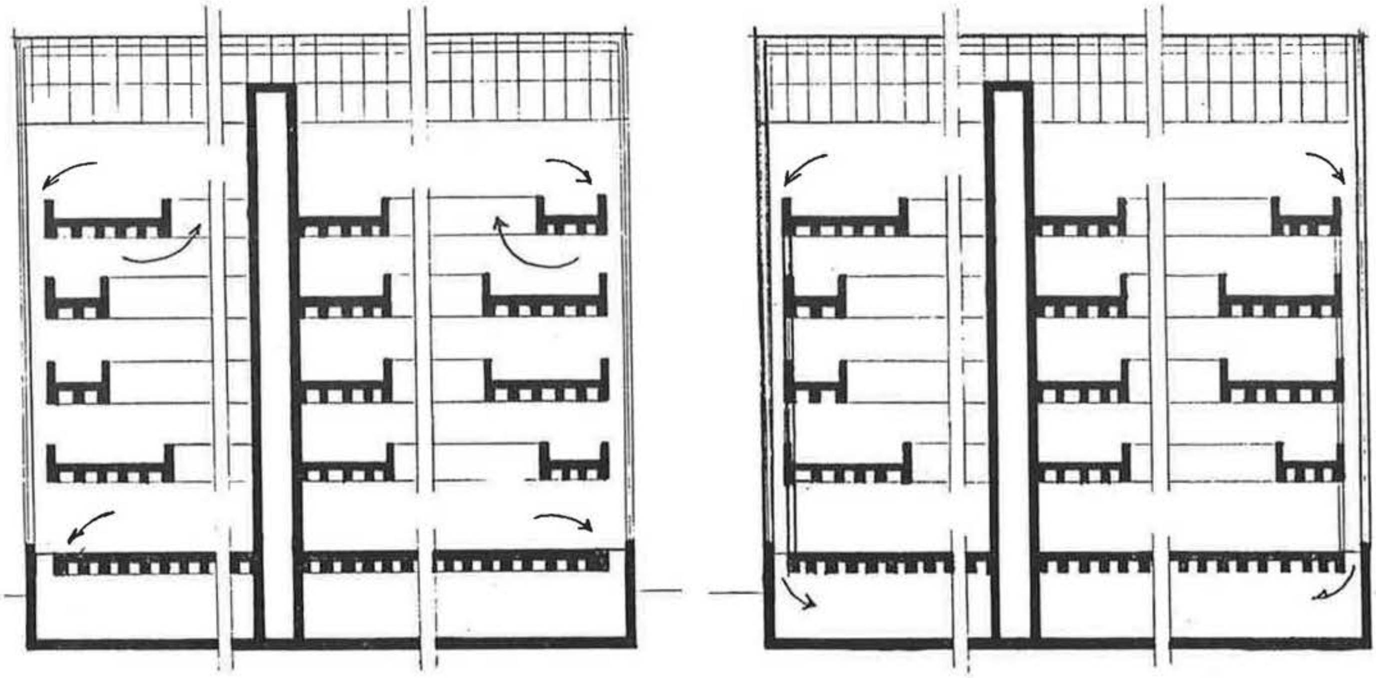


Figure 12 *College atrium: Concentrations of CO_2 and CO on the fifth floor (left) and in the open stairwell down from the first floor (right) measured in the atrium during a typical 24-hour period.*



Air stratification at College of Design   Air flow through "window shaft" in Atrium

Figure 13 *Proposed solution to reduce air stratification and to improve indoor air quality in college of design.*