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A SUMMARY OF ANALYTICAL METHODS AND CASE STUDY MONITORING OF ATRIA

J.R. Jones
Associate Member ASHRAE

M.B. Luther
Student Member ASHRAE

ABSTRACT

Atria are multistory spaces that provide a visually stimulating link between the interior and exterior environments through a skylight. Atria can be characterized by many thermal processes and conditions, such as dynamic air temperature stratification, extreme skylight surface temperature variations, differential interior surface temperatures, greater natural convection air velocities, and a multilevel zoning behavior. Unfortunately, these processes are not well understood by designers and, as a result, many atria are operational liabilities rather than assets. Part of the reason for this may be the lack of detailed research into this area and the fact that current energy analysis tools do not adequately account for the interactions among these processes. For these reasons, more study and the development of an energy model more applicable to these spaces are needed.

Several studies were conducted at a major university to increase our understanding of the thermodynamic behavior of these spaces. These studies were for existing and proposed spaces, and the methods included in-situ monitoring and scale modeling. The analytical methods include inspection of time-series plots, computer-generated thermal imaging, and multivariate linear regression. The scale-model studies used fluid mapping and wind tunnel tests to examine the opportunities for naturally venting the excess heat that accumulates near the skylight. The results from these studies led to recommendations to the university architect, utilities department, and consulting engineers for more efficient design and operation of these spaces. The analytical procedures, the results, and their implications for HVAC system operation are discussed.

INTRODUCTION

The atrium has recently emerged as a popular design element for architects. This might be due to the visual dynamics of these spaces with their multistory proportions and utilization of daylight. Spaces such as these are also often popular among real estate developers because of the higher rents that can be collected in buildings with such amenities. While atria do have advantages, they too often create operational liabilities with high costs for heating and cooling. This is, in part, due to the architect's and mechanical engineer's lack of recognition for the thermal processes that take place in these spaces. For example, atria typically will experience large temperature differences between the upper and lower zones. With an understanding of this stratification and a recognition of the operating and ambient weather conditions that create it, strategies can be developed to reduce the need for heating or cooling.

Several buildings with atrium spaces have been constructed during the past decade on a major university campus. In an effort to improve our understanding of the thermodynamic behavior and to develop energy conservation strategies for these and future designs, several studies were conducted. These included monitoring of two geometrically different atria for both passive and active conditions during winter and summer operation. Data collected for these spaces were analyzed using time-series plots, computer-generated thermal imaging, and multiple linear regression. In addition to the in-situ monitoring, the possibilities for naturally ventilating a proposed atrium were studied using a fluid mapping table and wind tunnel. These studies led to proposals for more energy-efficient atrium design and heating, ventilating, and air-conditioning (HVAC) system operation. The analytical procedures, their results, and recommendations are presented in this paper.

IN-SITU MONITORING

To better understand their thermodynamic behavior, two geometrically different atria were studied. The first was a long, narrow space with a high sectional aspect ratio. Located in the electrical engineering and computing science (EECS) building, this four-story space serves as a circulation spine through the building (see Figures 1 and 2). The atrium is 300 feet long (91.4 m), 30 feet wide (9.1 m), and 70 feet high (21.3 m). Other than the bridges that span the upper floors, only the lowest level is occupied.

The second atrium is located in the chemistry building. This space is square in plan, four stories tall, and has a small sectional aspect ratio (see Figures 3 and 4). This space is 94 feet long (28.6 m), 94 feet wide (28.6 m), and 77 feet high (23.5 m). Although these spaces are geometri-

James R. Jones is an engineering research associate and Ph.D. candidate and Mark B. Luther is a Ph.D. candidate in the College of Architecture and Urban Planning, University of Michigan, Ann Arbor.

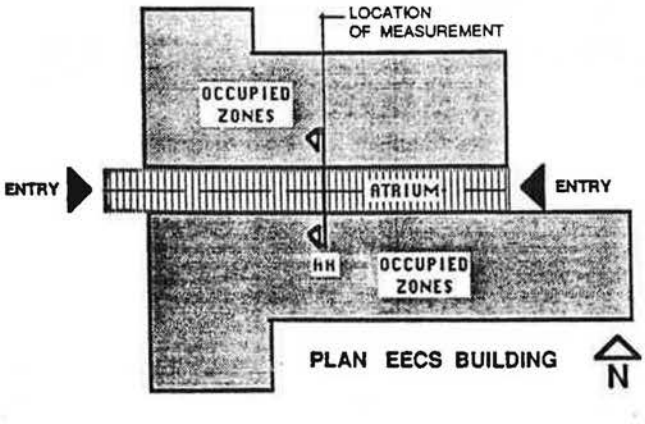

Figure 1 *Plan of EECS building.*

cally very different, they are volumetrically similar. Both spaces have a skylight roof with similar transmittance properties. Also, the interior construction is brick and block for both, although the EECS atrium has some wall areas with furring and gypsum board over the block.

During 1989-1990, copper-constantan thermocouples were suspended in a center section of the EECS atrium (see Figure 2). These were located vertically in the center of the space at approximately the midpoint of each floor level and near the skylight. Thermocouples were also located on the surface and 5 inches (12.7 cm) away from both the north and south walls. Due to limitations on the data recorder, the wall temperature measurements were only taken for the upper and lower zones (see Figure 2). In addition to the interior temperatures, outside glass surface and outdoor air temperatures were recorded, as well as global solar radiation and wind speed near the skylight.

Similar to the EECS building, measurements in the center of the chemistry building atrium were made for each floor level and near the skylight. Unlike the EECS building, however, thermocouples were located along all four walls for each level (see Figure 4). Air temperatures 5 inches (12.7 cm) away from each wall were taken for the upper and lower zones. Outside air temperature, solar radiation, and wind speed were measured near the skylight. These measurements were made from 1990 through 1991.

For both atriums, recordings were made at five-minute intervals during winter and summer and with the air-conditioning system off or on for several consecutive days.

Data Analysis

From the monitored data, three analytical approaches were used. For the EECS atrium, time-series plots and computer-generated thermal imaging were used to increase our understanding of the thermodynamic behavior of this space. Multiple linear regression was used to compare the responses of the two atria to changing weather conditions.

Time-Series Plots Recordings for the EECS atrium were plotted so that variations in interior and exterior

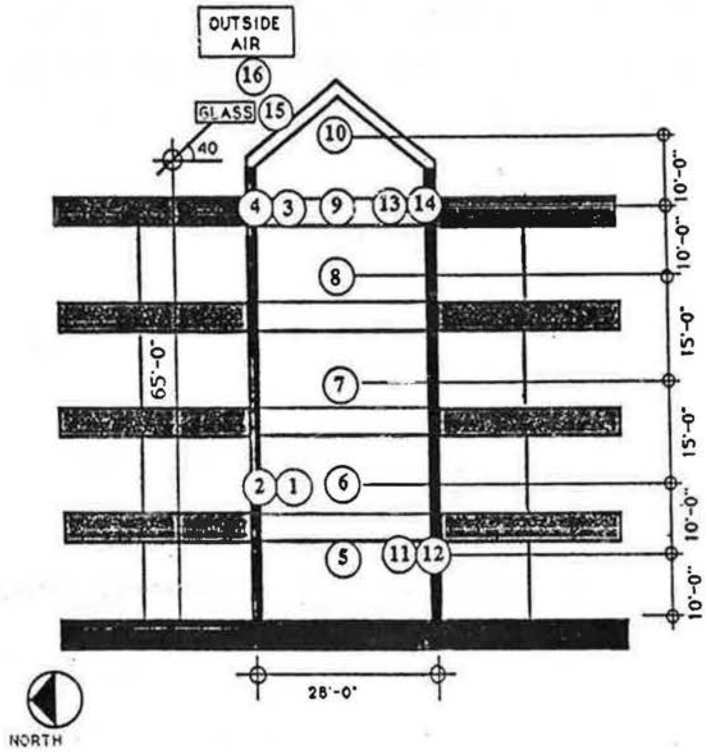

Figure 2 *Section of EECS—thermocouple location.*

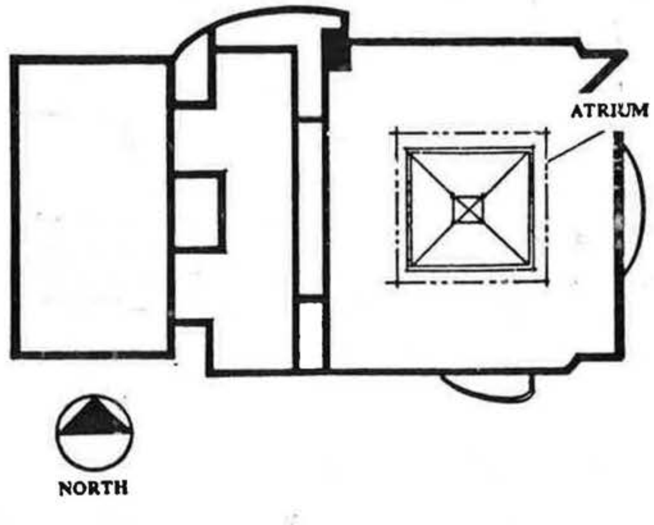

Figure 3 *Plan of chemistry building atrium.*

conditions could be easily observed. For example, Figure 5 shows the variations in the inside air temperature for different vertical locations for a 24-hour period in July. For these recordings, the air-conditioning system was off. As shown, the difference in inside air temperature is only a few degrees during the night. During the day, however, the difference between the upper and lower levels varies by as much as 27°F (15°C). Also notice the larger diurnal temperature variation near the skylight when compared to

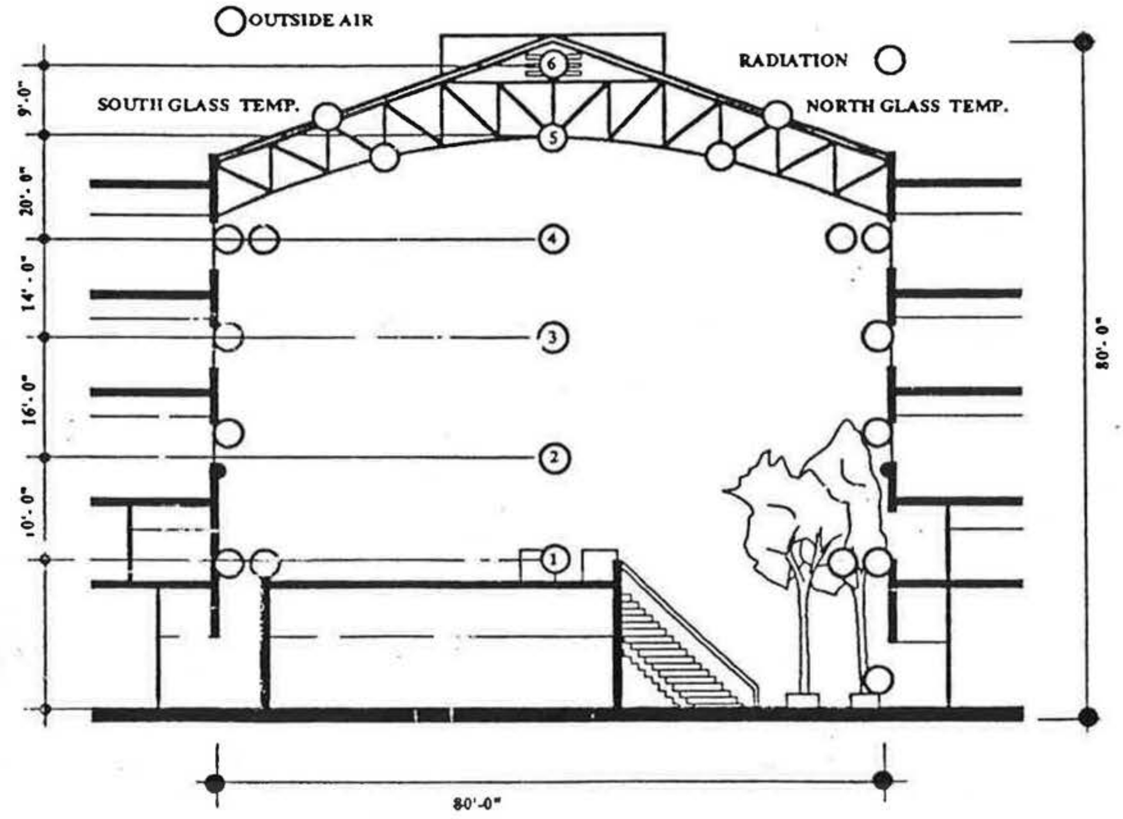

Figure 4 Section of chemistry building atrium with thermocouple location.

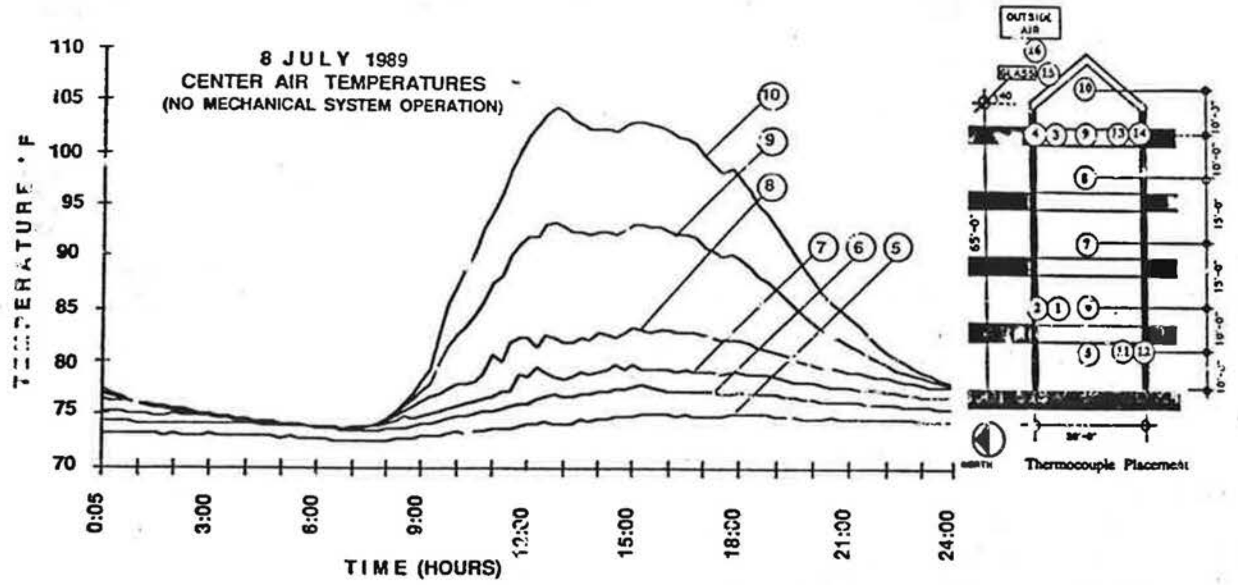

Figure 5 EECS atrium center air temperatures—July 8.

the recordings taken at the lowest level. This begins to suggest a two-zone response pattern, as will be discussed later. Figure 6 shows that the overall pattern remains the same for winter conditions, although the inside air temperatures are lower than for the summer. The existence of stratification and seasonal and diurnal variations in thermal response must be recognized when designing and conditioning multistory spaces.

Thermal Imaging Again, to enhance our understanding of the thermal processes that take place in atria, a computer-generated thermal imaging procedure was used. For this, recordings for the EECS atrium data were converted for use with the university's graphics editing software. For each recording location, the time-series data were structured to serve as input to the program. Sectional dimensions of the atrium were input to the program, as well

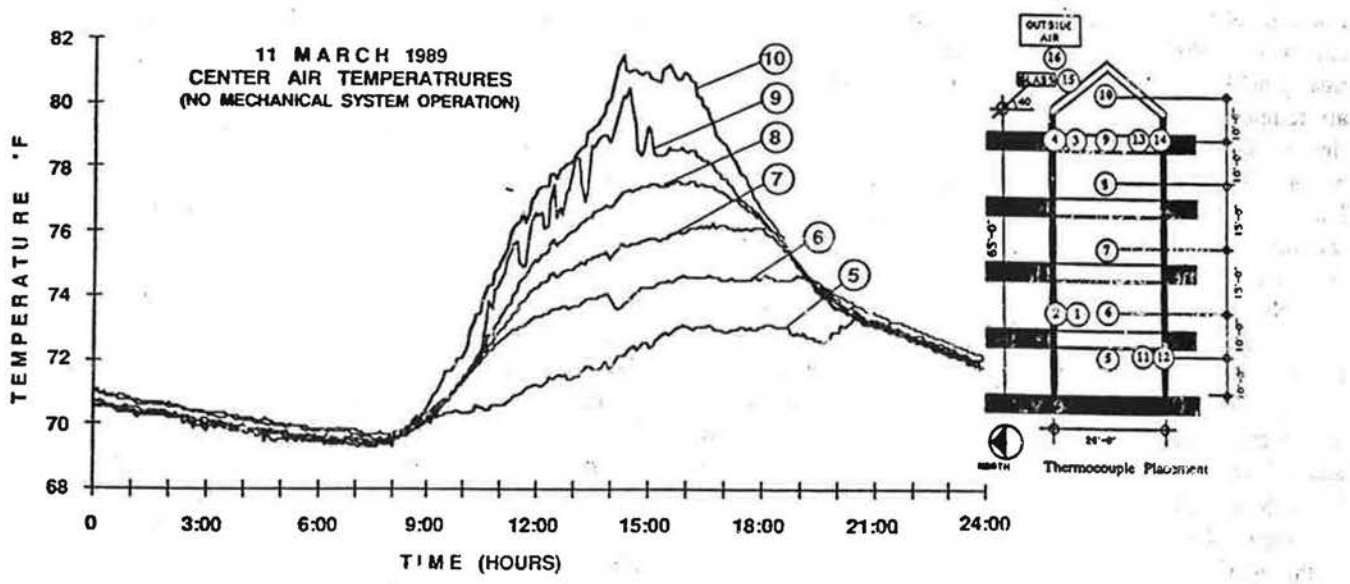

Figure 6 *EECS atrium center air temperatures—March 11.*

as the temperature data for each location. The interior of the atrium was divided using a two-dimensional Cartesian grid system with nodes located in the center of each grid modulus. Approximately 110 nodes were used. For the nodes corresponding to the locations for the recorded data, the temperatures were assigned directly. For the intermediate nodes, the temperatures were estimated using linear interpolation and an iterative calculation procedure. Colors were assigned to the temperature scale. For example, red represented hot, while blue was cold. The results from this procedure were displayed and redrawn for different weather conditions. Figure 7 shows the rather uniform cold temperatures that were present at 7:00 a.m. on March 10. Figure 8 indicates that by noon of the same day temperatures near the skylight were considerably warmer and a large degree of stratification existed. This imaging approach was useful for interpreting the data and for understanding the dynamics of the stratification phenomenon. It was also used as a teaching tool for demonstrating the dynamics of these spaces to visually oriented architectural students.

Multiple Linear Regression Since the data for the two atria were collected over two different recording periods, time-series plots and thermal imaging could not be used to directly compare the spaces. Also, while these methods allowed for qualitative evaluation, they were not quantitative in the sense of providing an indication of the relative impact of climatic variables on inside air temperature. For these reasons, multiple linear regression was used as an alternative evaluation method.

Data Structure Monitored data for each atrium were entered into the university's mainframe computer and organized sequentially. The complete time-series for the

Figure 7 *Results of a computer thermal imaging model, 7:00 a.m., March 10.*

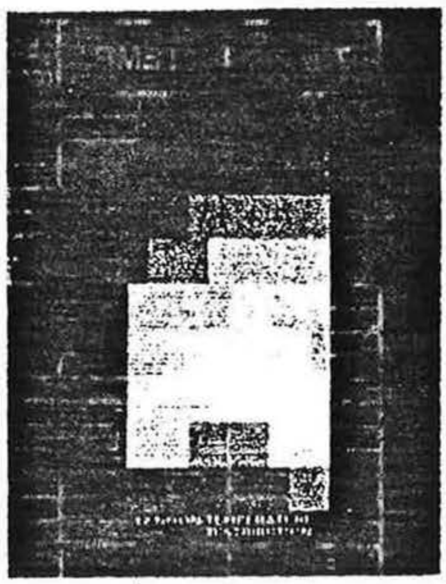

Figure 8 *Results of a computer thermal imaging model, noon, March 10.*

lower level was entered first, while the last section of the data was for the upper measurements (see Figure 9). Each case (line) has values for the inside air temperature, outside air temperature, global solar radiation, wind speed, and time of day. Dummy variables for the HVAC operation (1 = on, 0 = off) were created and added to the data. Dummy variables were also used to indicate the height of the measurement above the atrium floor. For example, with six vertical measurement locations, six bilevel dummy variables were created. For recordings taken at the lowest level, the first variable is set to one and all others to zero (1, 0, 0, 0, 0, 0). For the sixth level, the sequence would be (0, 0, 0, 0, 0, 1). These variables allowed the differences in temperature with height to be quantified. Solar altitude and azimuth angles were calculated and added to the data for each recording.

Regression Analysis and Results An early objective of this work was to qualitatively and quantitatively understand the thermodynamic behavior of these two geometrically different spaces and compare their behavior. To do this, an expression was needed for the relationship between variables such as inside air temperature and solar radiation. Using multiple linear regression and a least-squares fitting procedure, equations such as Equation 1 were derived for each space.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + ... + \beta_k X_k + e \quad (1)$$

where

Y	=	predicted dependent variable,
β_0	=	intercept,
$\beta_1 . . \beta_k$	=	partial slope coefficients,
$X_1 ... X_k$	=	independent variables,
e	=	error.

A potential problem with multiple linear regression and ordinary least squares (OLS) is that, for time-series data, the residuals are likely to be autocorrelated. This violates an important assumption for OLS. An alternative analytical approach is generalized least squares (GLS). GLS helps reduce or eliminate the autocorrelation problem and provides reliable tests for significance from which inferences for the independent variables can be drawn (Schroeder et al. 1989; Berry and Feldman 1990). For this reason GLS was used for this study.

As indicated by the time-series plots and thermal imaging, an important consideration in atrium design and operation is air temperature stratification. Stratification is defined as the difference between the maximum temperature (normally at the highest level) and the minimum temperature (at the lowest level) (Chastain and Colliver 1989). Two equations were derived, one for each atrium, that predict the temperature difference between the upper and lower zones as a function of ambient weather conditions and solar position (see Equations 2 and 3). The equations were derived for passive conditions with the air conditioners off.

$$\text{EECS TDIFF} = 23.48 + .143\ \text{TOA} + .005\ \text{RAD} + .03\ \text{Log Wind} - .29\ \text{SOLZEN} \quad (2)$$

(18.5) (9.5) (2.4) (.6) (-46.0)

$$\text{CHEM TDIFF} = 13.91 + .326\ \text{TOA} + .004\ \text{RAD} + .19\ \text{Wind} - .068\ \text{SOLZEN} \quad (3)$$

(6.5) (14.0) (3.1) (1.97) (-5.5)

where

TDIFF	=	predicted temperature difference from upper to lower zone (°F),
TOA	=	outdoor air temperature (°F),
RAD	=	global solD radiation (Btu/ft^2),
Log Wind	=	log transformation of wind speed (fps),
Wind	=	wind speed (fps),
SOLZEN	=	solar zenith angle (degrees).

TIME	TEMP.	LOCATION (COORDINATE)	HVAC OFF / ON	WEATHER PARAMETERS	ASSIGNMT
1	XX1	10, 70	0	XX1 YY1 ZZ1	POINT #1
2	XX2	10, 70	0	XX2 YY2 ZZ2	
3	XX3	10, 70	0	XX3 YY3 ZZ3	
4	XX4	10, 70	0	XX4 YY4 ZZ4	
*	*	10, 70	0	*	
*	*	*	*	*	
1	XX1.2	10, 60	0	XX1 YY1 ZZ1	POINT #2
2	XX2.2	10, 60	0	XX2 YY2 ZZ2	
3	XX3.2	10, 60	0	XX3 YY3 ZZ3	
4	XX4.2	10, 60	0	XX4 YY4 ZZ4	
*	*	10, 60	0	*	
*	*	*	*	*	
1	XX1.3	10, 70	0	XX1 YY1 ZZ1	POINT #3
2	XX2.3	10, 70	0	XX2 YY2 ZZ2	
3	XX3.3	10, 70	0	XX3 YY3 ZZ3	
4	XX4.3	10, 70	0	XX4 YY4 ZZ4	
*	*	10, 70	0	*	
*	*	*	*	*	
ETC.	ETC.	ETC.	ETC.	ETC.	ETC.

Figure 9 Data structure used for regression analysis.

As shown in both equations, the most significant variables are outside air temperature (TOA), sun position as represented by the zenith angle (SOLZEN), and global solar radiation. Although wind speed was included in both equations for theoretical reasons, it is shown to be quantitatively and statistically less significant than the other variables.

For both spaces, stratification increases directly with outside air temperature, although the influence is larger for the chemistry building. This will be discussed later. Also, as the solar zenith angle increases, meaning we are moving away from solar noon, the magnitude of the temperature difference decreases. Not surprisingly, the influence from solar position is greater for the EECS building. This is probably due to the narrow proportions of this space and the more localized solar influence near the skylight. This will also be discussed later in greater detail.

Figure 10 compares the predicted temperature difference between the upper and lower zones for both atrium geometries at different outdoor air temperatures and for three levels of global solar radiation (0, 70, and 270 Btu/ft²·h [0, 220, and 850 W/m²]). Wind speed was held constant for all calculations. Solar altitude angles were calculated for the hours when the selected values for global solar radiation were most likely to occur. As shown for both spaces, the temperature difference between the upper and lower zones increases as outside air temperature and solar radiation increase. However, the stratification is larger in the building with higher sectional aspect ratio (EECS) for similar weather conditions.

Using these same equations, the predicted temperature differences between the upper and lower zones are shown in Figure 11 for different hours of a typical day for Ann Arbor, Michigan, for January 21, April 21, and July 21 for each space. Similar to Figure 10, Figure 11 shows an increase in stratification as we change from winter to summer conditions. Both figures also indicate that, with little or no solar radiation and cold outdoor temperatures, these spaces experience a temperature inversion with interior air temperatures near the skylight colder than at the floor. This inversion is likely due to the heat transfer from the warm inside air through the skylight to the outdoors and the radiant heat exchange between the upper walls, skylight, and night sky. The magnitude of the inversion is approximately the same for both spaces (about −5°F to −7°F at 30°F outdoor air temperature (−2.8°C to −3.9°C at −1.1°C).

The recognition and quantification of this inversion are important for at least two reasons. First, it is under these conditions that condensation of moisture on the inside surface of the skylight is likely to occur. For this, strategies must be developed to prevent the build-up of moisture on the glass surface. Second, under these conditions, downdrafts of cold air are likely to occur, creating discomfort for the occupants below.

As temperature and solar radiation increase, Figures 10 and 11 suggest that both spaces experience noticeable temperature stratification. Interesting, however, is the larger degree of stratification in the EECS building when compared to the chemistry building for similar outdoor air temperature and solar radiation conditions. For example, Figure 10 shows that at about 70 Btu/ft²·h (220 W/m²), the EECS atrium has an approximately 5°F (2.8°C) larger temperature difference between the upper and lower zones than the chemistry building. As the level of solar radiation increases to about 280 Btu/ft²·h (850 W/m²), the stratification increases in the EECS building to about 25°F (14°C). For the chemistry building at 280 Btu/ft²·h (850 W/m²), the predicted stratification is only about 16°F (8.9°C), nearly 10°F (5.5°C) less than for the more cavernous EECS atrium. This is also shown in Figure 11. Furthermore, Figure 11 shows that the stratification is largest in July, when warm outdoor conditions and high solar angles and radiation prevail. As expected, the stratification is predicted to be largest during the middle of the day, decreasing during the nighttime. As previously mentioned, due to conduction through the skylight, both spaces experience inversions during the night when colder temperatures are present and there is no solar radiation.

The larger stratification for the EECS building is probably due to its two-zone behavior (upper and lower) and the more localized impact from solar radiation near the skylight. Because of the deeper, more cavernous geometry for this space, the direct solar radiation does not penetrate as deeply as in the more open chemistry building (see Figure 12). This implies that the lower level of the EECS building is less influenced by solar radiation than the upper zone, which leads to large differences between the zones. For the chemistry building, on the other hand, the air temperature is more uniform as the solar rays penetrate much deeper.

The previous results describe the stratification for each space as a function of outdoor conditions and solar geometry. A second analysis was conducted to determine the average change in inside air temperature for different vertical locations. Two equations were derived for predicting inside air temperature using height as an independent variable. Equation 4 predicts the inside air temperature in the EECS atrium, while Equation 5 is for the chemistry building.

$$\text{(EECS) TIN} = 78.3 + .017\ \text{TOA} + .0014\ \text{RAD} + .012\ \text{Wind} - .07\ \text{Solzen} + 1.02\ \text{HT2} \quad (4)$$

(48.4) (1.8) (4.08) (1.91) (-12.0) (0.5)

$$+ 1.7\ \text{HT3} + 2.6\ \text{HT4} + 4.3\ \text{HT5} + 6.16\ \text{HT6}$$

(0.9) (1.25) (2.1) (3.0)

$$\text{(CHEM) TIN} = 76.8 + .11\ \text{TOA} + .005\ \text{RAD} + .04\ \text{Wind} - .06\ \text{Solzen} + .56\ \text{HT2} \quad (5)$$

(60.1) (38.9) (3.1) (11.9) (-10.5) (2.7)

$$+ 1.0\ \text{HT3} + 1.9\ \text{HT4} + 4.5\ \text{HT5} + 6.2\ \text{HT6}$$

(5.4) (8.3) (21.8) (28.1)

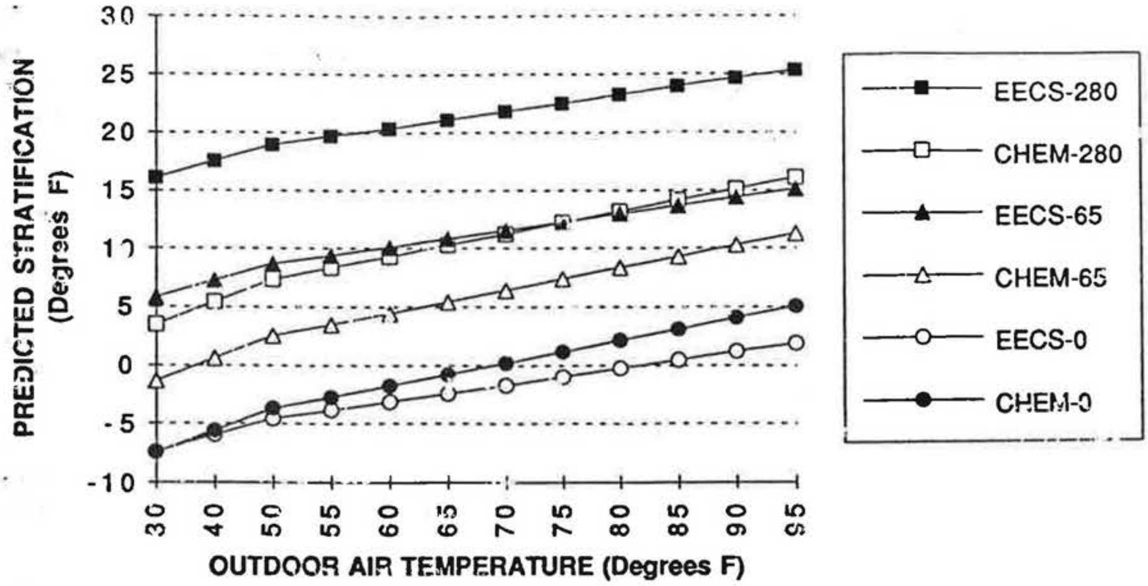

Figure 10 *Comparison of predicted temperature differences for upper and lower zones for various outdoor temperatures and solar radiation.*

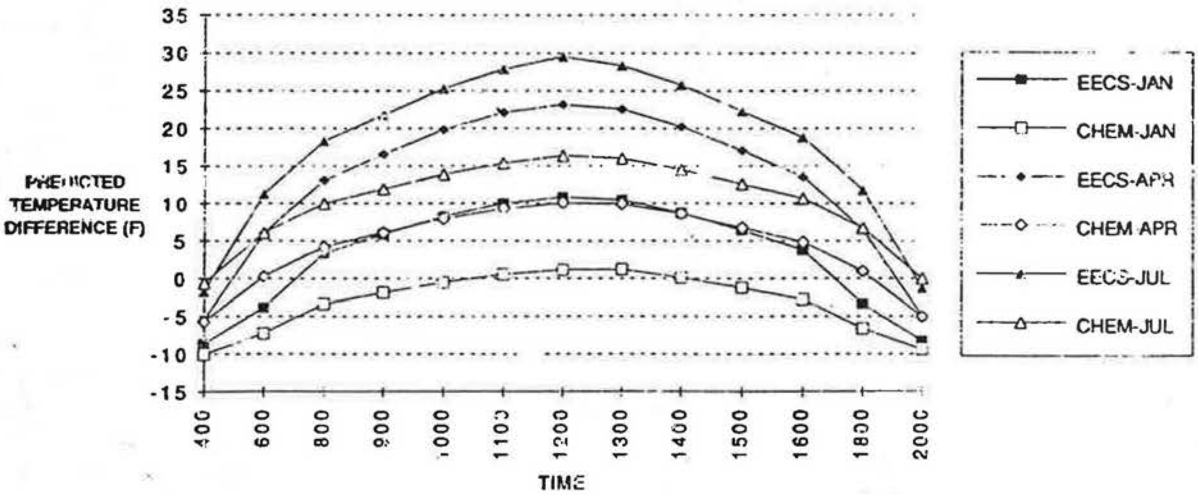

Figure 11 *Comparison of predicted temperature differences for upper and lower zones for various seasonal conditions.*

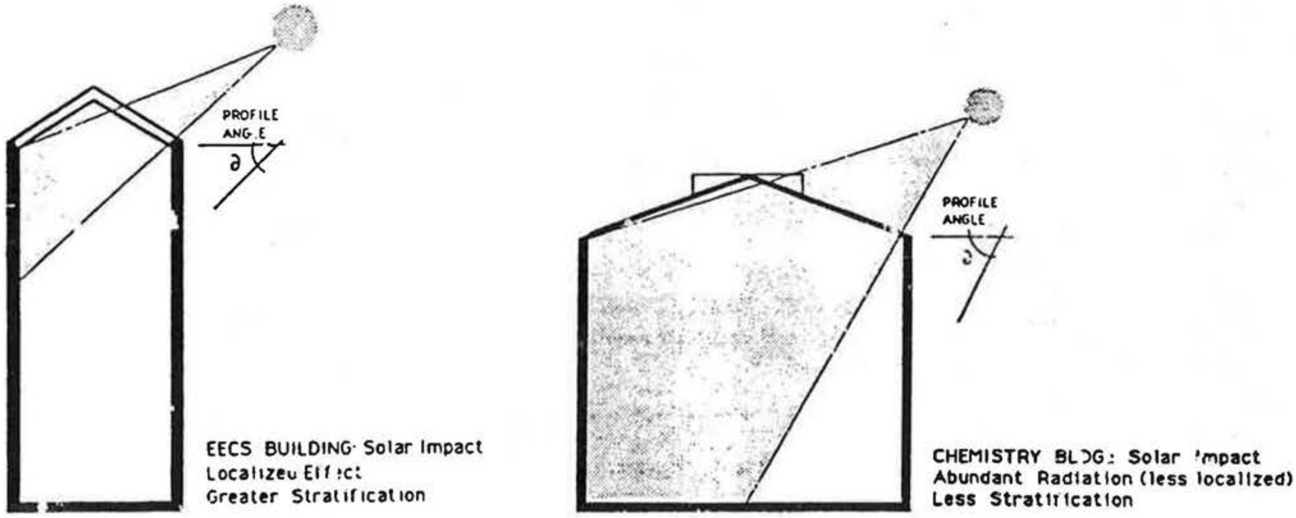

Figure 12 *A comparison of solar impact and aspect ratio for both atria.*

where

TIN	=	predicted inside air temperature (°F),
TOA	=	outdoor air temperature (°F),
RAD	=	solar radiation (Btu/ft²·h),
Wind	=	wind speed (fps),
Solzen	=	solar zenith angle (degrees),
HT2-HT6	=	average temperature increase for each vertical location compared to the lowest zone (HT1). The values of HT2-HT6 are bi-level (either 0 or 1).

The partial slope coefficients for HT2 through HT6 are plotted for each atrium in Figure 13. This figure seems to confirm earlier findings that the average degree of stratification is greater in the EECS building than in the chemistry building.

An interesting aspect of Figure 13 is the distinct change in slope that occurs at about the 48-foot (14.6-m) level in the EECS building. This indicates a two-zone behavior of this space, where the temperature gradient is much greater for the upper zone near the skylight than in the lower zone. This also seems to imply that the impact from solar heat gain through the skylight is localized. The plot for the chemistry building coefficients, on the other hand, shows no clear point of transition in slope but a more gradual increase as we move vertically through the space. This seems to suggest a more thoroughly mixed air volume and less localized solar impact, as previously shown.

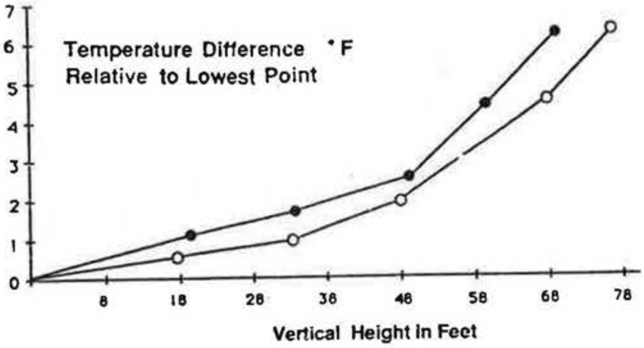

Figure 13 *Comparison of average increase in interior air temperature for various vertical locations.*

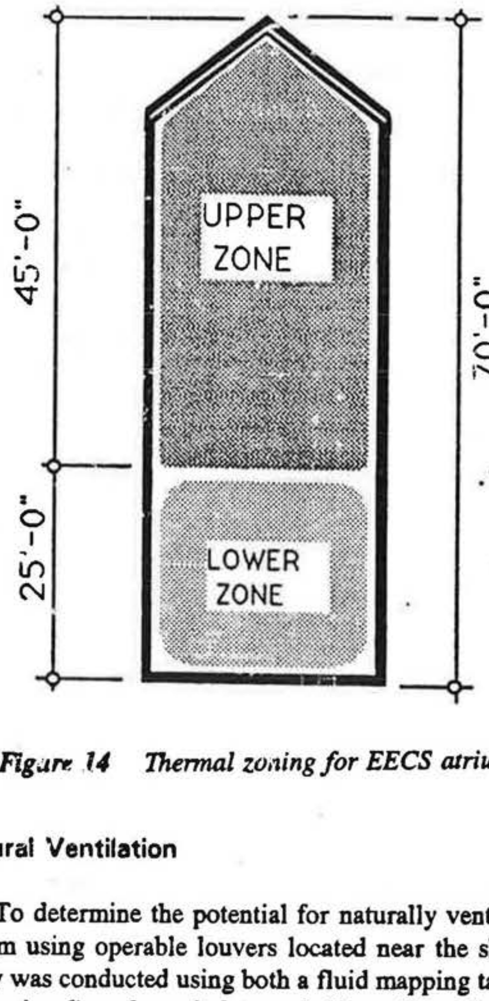

Figure 14 *Thermal zoning for EECS atrium.*

IMPLICATION FOR RESULTS

The results from the in-situ monitoring indicate that stratification is common for both atria, although it is greater for the more cavernous EECS building. Figure 13 suggests that two distinct zones exist for the EECS building (see Figure 14). For this space, the upper zone is influenced by solar heat gain through the skylight while the lower zone experiences less fluctuation. This has important consequences for the design and operation of systems serving spaces such as this.

Cooling Operation

During the cooling season when stratification is greatest, the upper zone should be conditioned separately from the lower zone. When excessive heat is collected through the skylight, upper-level vents should be opened to allow for natural ventilation or exhaust fans should be turned on. Because comfort conditions are only needed for the occupied space, the lower zone should be conditioned separately (see Figures 15 and 16).

Natural Ventilation

To determine the potential for naturally ventilating an atrium using operable louvers located near the skylight, a study was conducted using both a fluid mapping table (two-dimensional) and a wind tunnel (three-dimensional). For both techniques, scale models were constructed for a proposed university building (see Figure 17). Figure 18 shows the two-dimensional cross-sectional model used for the fluid mapping table. As shown, with water flowing at approximately 15 mph and openings in the skylight kneewalls, a distinct flow pattern develops for the upper zone of the atrium. This suggests that the possibilities for achieving adequate natural ventilation were good.

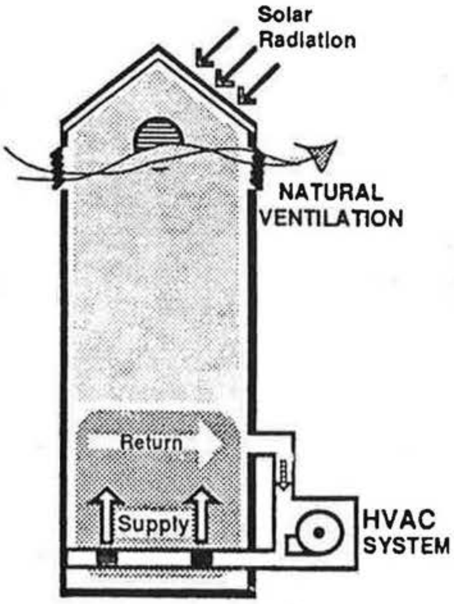

Figure 15 *Summer stratification and natural ventilation.*

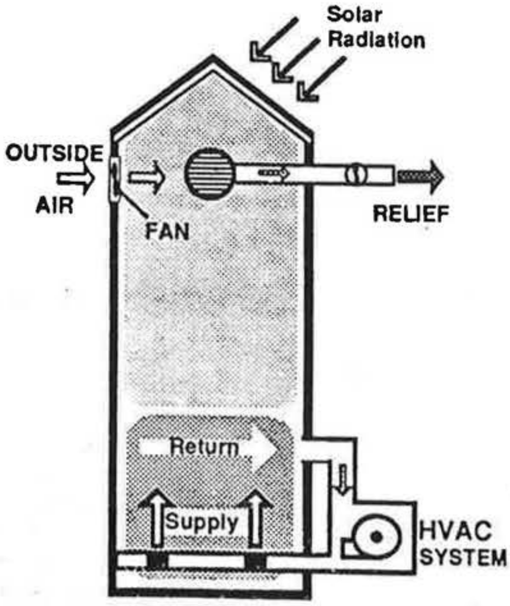

Figure 16 *Summer stratification and active operation.*

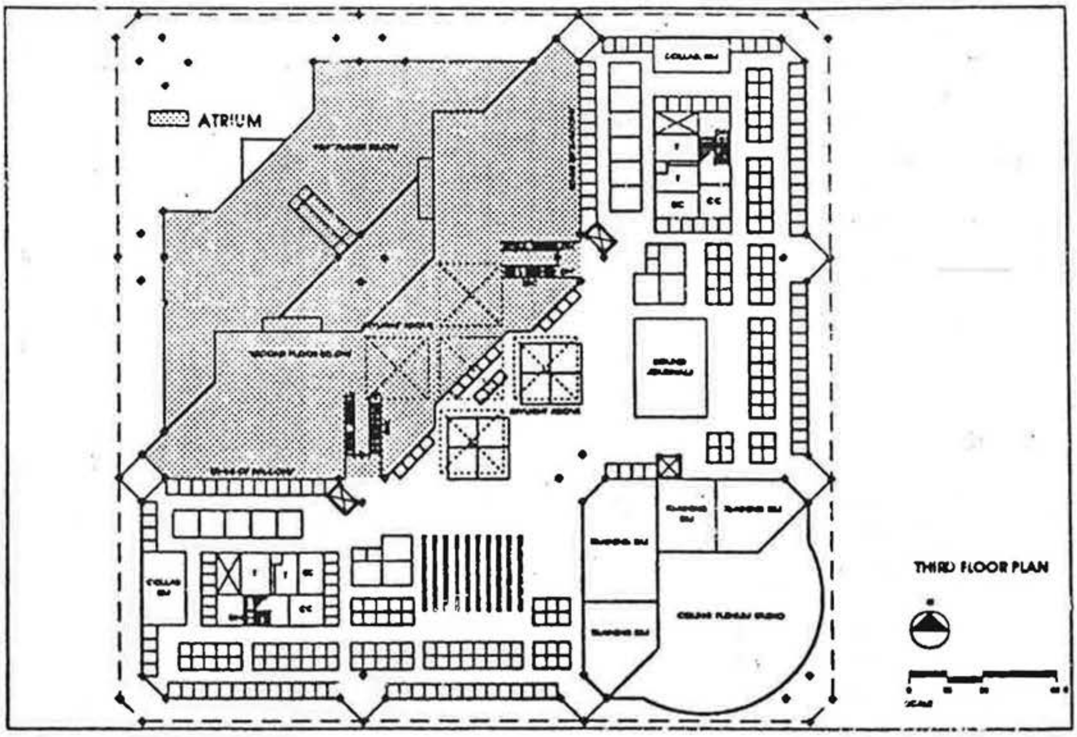

Figure 17 *Plan of proposed university building.*

Using the three-dimensional model shown in Figure 19, a similar study was performed in the wind tunnel at the university's College of Engineering. By filling the atrium model with smoke, the ventilation potential could be determined by observing the time required to evacuate the smoke at different wind velocities. The wind tunnel tests confirmed the results from the fluid mapping table as a distinct stream of smoke was observed from the outlet opening in the atrium model. Both the fluid mapping and wind tunnel tests indicated that natural ventilation of the atrium's upper zone could be achieved at wind speeds as low as 5 mph. When wind speeds are too low or adjacent obstructions prevent the application of natural ventilation, exhaust fans can be used to achieve similar results.

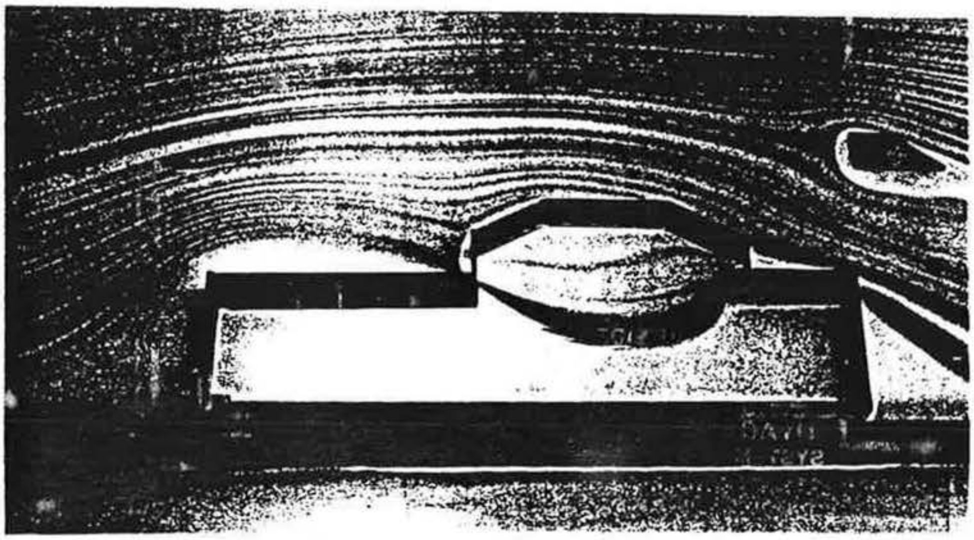

Figure 18 Fluid-mapping results using two-dimensional scale model.

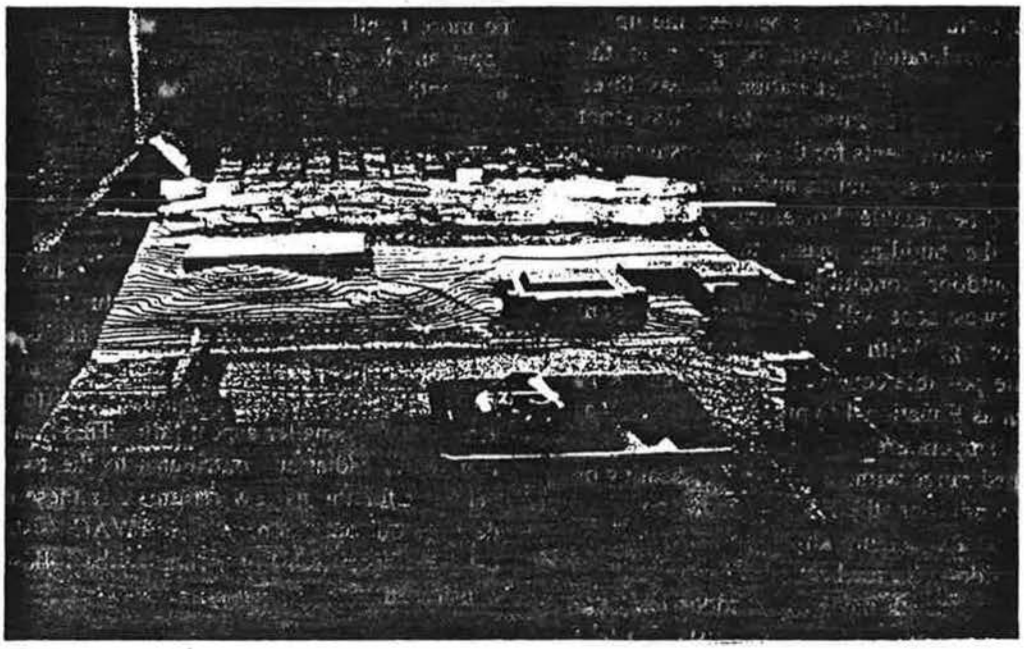

Figure 19 Three-dimensional scale model for wind tunnel testing.

Economizer Operation

One of the most obvious energy-conserving opportunities involves the intake of outside air to reduce the need for mechanical cooling. For example, hot return air can be exhausted and exchanged for cool outside air (see Figure 20). Typically referred to as economizer control, this strategy can significantly reduce the need for mechanical cooling. In a climate such as Ann Arbor, Michigan, this control strategy is typically used when outside air temperatures are between 55°F (13°C) and 72°F (22°C). Above this, it is assumed that the heat content of the outdoor air (including water vapor) is greater than the return air, and the controller closes the outside air intake to a minimum position. The previously mentioned temperature range for the economizer operation is appropriate for typical applications, such as offices where return air temperatures are between 75°F and 80°F (24°C and 27°C). For atria, however, where temperatures returned from the upper zone can be in excess of 100°F (38°C), energy-saving opportunities are missed if the economizer temperature range is kept at 55°F to 72°F (13°C to 22°C). To reduce energy consumption, an enthalphy controller should be used, which compares the total heat content of the return and outside air and positions the dampers to condition the air with the lowest cooling requirement. While this method of control offers energy savings for typical applications, it is even more appropriate for atrium HVAC systems.

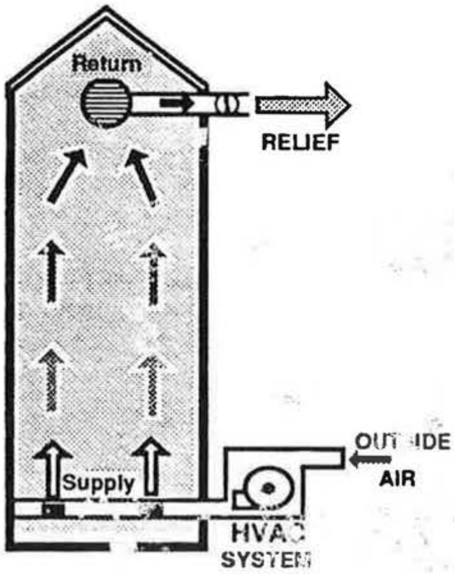

Figure 20 *HVAC system economizer operation.*

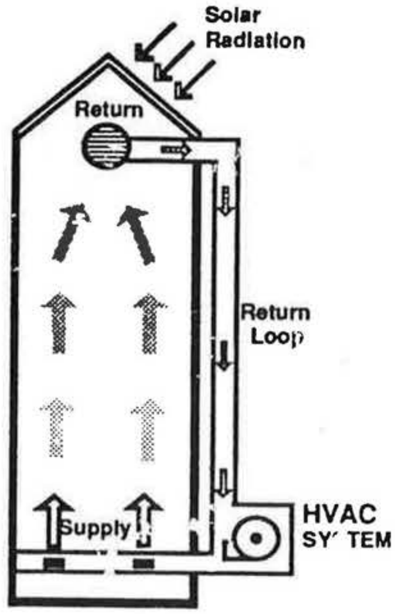

Figure 21 *Winter destratification operation.*

Heating Operation

With large temperature differences between the upper and lower zones, consideration should be given to the HVAC system's design and heating operation. At least three situations should be considered. First, due to the less strict thermal conditioning requirements for the activities normally associated with atria, the scheduling and operation of the HVAC system should be flexible. For example, due to the thermal inertia of the building mass, there are many combinations for outdoor conditions when the interior temperature in the lowest zone will be comfortable without mechanical conditioning. With an energy management system installed, one possible control strategy might be to use an equation such as Equation 4 to predict the conditions when the inside air temperature for the occupied level will be within a predefined range without mechanical heating or cooling. For these conditions, the HVAC system could be shut off and the space temperature allowed to float.

The second consideration for heating operation occurs during clear winter days with moderate outdoor temperatures. With these conditions, stratification exists. To take advantage of this and reduce the need for heat input, the HVAC system should extract the warm air from the top of the atrium and transfer it to the lower zone (see Figure 21). This destratification might be achieved by separate fans located in the atrium or by designing a "flexible" HVAC system that can allow for this operating mode.

The third mode of winter operation occurs during overcast days and nights. During periods with little or no solar radiation and a net heat loss through the skylight, the air temperature in the upper level is less than in the lower zone (see Figures 10 and 11). With a dynamic HVAC system that combines operating strategies such as shown in Figures 16 and 21, the upper and lower zones can be conditioned to different temperatures. For example, the upper zone only needs to be conditioned to prevent condensation on the glass surface. Because comfort is not an issue, lower temperatures are acceptable. In the lower occupied zone, comfort is important and the space temperature must be more tightly controlled. By separately conditioning the upper and lower zones in this way, less heating is required than with a single-zone solution.

CONCLUSIONS

While the results presented in this paper are specific to the cases studied, more general conclusions can be drawn. For example, the degree of temperature stratification seems larger for atriums with a large sectional aspect ratio. This is due to the more localized influence from solar radiation at the top of the atrium when compared to the more open atrium with a smaller aspect ratio. This localized influence from solar radiation contributes to the two-zone thermal behavior for the narrow atrium. For these conditions, the design and operation of the HVAC system should be carefully specified. For example, the following should be considered:

1. The HVAC system(s) should be designed to condition the atrium as both two zones or a single zone depending on interior and ambient weather conditions.
2. Due to higher than usual return air temperatures, the economizer changeover temperature should be carefully reset or an enthalphy controller should be used.
3. Provisions such as operable louvers near the skylight should be installed to allow for natural ventilation and removal of heat that builds up near the skylight.
4. The less stringent thermal comfort requirements for atriums should be considered when controlling HVAC systems. For example, there are weather conditions when the atrium's interior air temperature will be comfortable without the need for heating or cooling. These conditions should be identified and incorporated into energy management strategies.

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