Passive Cooling: A Case Study of the Evaporation Phenomena

Raymond J. Alfini P.E.
Graduate Student
Arizona State University School of Architecture
Main Campus – PO Box 871605
Tempe, AZ 85287-1605

ABSTRACT

Passive cooling strategies require strict adherence to the physical world. Ones imagination creates the flow of ideas that can blossom into a comfortable setting, but the reality of design, construction and cooperation has to be observed and accepted. Physical laws govern as natural processes follow the path of least resistance. In order for us to overcome these laws extra energy is required. That is why passive cooling designers must investigate how to create a comfortable setting by understanding how natural procedures work. The evaporative cooling phenomena and the humidification phenomena are similar processes, but they can have opposing results with respect to the comfort level. A review of each process reveals that air movement plays an important role in determining which phenomena will be present.

EVAPORATIVE HUMIDIFIER OR COOLER?

Recycling air across a moisture source raises the moisture content of this air until saturation. If this air is heated as it recycles within a system it will be able to hold even more moisture. A humidifier works in this manner.

An evaporative cooler distributes moisture to air in order to cool the air by an adiabatic process known as wet bulb depression. This cooled air then travels through the building system gathering heat and leaves. The air passes through the moisture distribution location one time.

This report will investigate how a design change converted the unproven cooling system for the atrium of the Sandra Day O'Connor Federal Courthouse mist evaporative cooler into a mist evaporative humidifier. The result has caused the public to perceive evaporative cooling as an undesirable mode of cooling because it cannot create a comfortable environment. Evaporative cooling is a major passive cooling concept and now it is thought of as no good. When, in fact it is a good process for hot and dry climates.

BACKGROUND OF THE $130 MILLION DOLLAR BUILDING

The atrium space in the Sandra Day O'Connor Federal Courthouse located in Phoenix, AZ was designed to convey the openness of the American judicial system. The atrium creates a public gathering space that is protected by glass and conditioned by passive energy systems to be a more comfortable environment than the outdoors. The atrium covers 56,450 square feet of the ground with two levels at the special proceedings court area. It is about 111 feet from the floor to the sunscreen located near the roof structure system. The atrium's exterior walls have single pane storefront type glazing in the north, east and upper level south gabled area walls. The cooling load is 2,820,000 BTUh and the heating load is 2,850,000 BTUh. Please review the Space Heat Transfer Loads Calculation Sheet located in Appendix A. The loads are high, as might be expected, because of decisions that were made during the design development process.

The Courthouse and Atrium do not adhere to Federal Guideline Specifications. The exterior glass for the atrium was to be a mix of bullet proof, laminated insulated glass and monolithic frit coated. Instead, all of the glass became monolithic glass, thereby increasing its conductivity. Federal Buildings are required to meet 10cfr435 subparagraph A and this building does not. The underground parking garage is located in the level below the ground level of the atrium and office space. Its ceiling/floor interface is an uninsulated concrete slab. The garage is ventilated 24/7 with 100,000 CFM of unconditioned outdoor air. This flow is sufficient to make the interior floor surface approach outdoor temperatures. The atrium's conditioning systems refrigerate conditioned return air from the office/courtrooms and distribute this air along the edge of the balconies as "spill air". The spill air provides 70 tons of cooling to the atrium. The cost to makeup this air to return air conditions is 130 tons of refrigeration cooling for the office/courtroom systems.

There is no way to protect the atrium from dust storms, as there is no:

1. Filtering of the inflowing air.
2. Control of the atrium air flow.
    a. From the outside
    b. Exhaust of inside
3. Smoke detector system coverage, because the detectors have been disconnected due to numerous false alarms

MIST EVAPORATION

Reverse Osmosis water is supplied by high-pressure pumps to 1,000 misting nozzles located on the Southside just below the sunscreen. The flow-rate is 16.4 gallons per minute or 3,723L/hr. Using a modified equation D.10 from the <u>ASHRAE Cooling and Heating Load Calculation Manual, 2nd Edition</u>, the minimum required cubic feet per minute CFM of air, to evaporate that much water is:

CFM = (Mw**v*)/(60*(*W2-W1/*))

Where: Ambient outside air conditions are 107°F db/71°F wb and this air is saturated to 71°F db. Mw is the mass of water in pounds/hr using 8.33 lbs of water per gallon of water or 8,197 pounds per hour, *v* is the specific volume of ambient air or 14.48 cubic feet per pound of dry air, *W2* is the moist air Humidity ratio or 0.016 pounds of moisture per pound of dry air, *W1* is the outside air Humidity ratio or 0.008 pounds of moisture per pound of dry air

CFM = 247,000 CFM.
This quantity of air has a cooling value to the Atrium of Q = 1,540,000 BTUh.

The water production and storage system has the potential to grow legionella bacteria. This pure water system does not conform to ASHRAE Guideline 12-2000 <u>Minimizing the Risk of Legionellosis Associated with Building Water Systems:</u> Sections 8.5.5 Misters.

UNCOMMISSIONED

The performance of the passive cooling system has never been measured and verified. The mist flows directly into the atrium above the sixth floor balcony. It saturates and cools air, thereby making the air heavier so that it falls towards the floor. The diffusion function drives moisture throughout the atrium, thereby humidifying the space. The misting system is controlled by a standard HVAC control system that will turn on the mist by the high temperature set-point. The system will turn off the mist by the make of:

1. Low temperature set-point
2. High humidity set-point

When the outdoor air temperature is equal to or greater than 84°F db/57°F wb the misting system shuts down on high humidity and not the temperature set-point. One can deduce that the system is performing as an evaporative humidifier and not an evaporative cooler.

By reviewing the Space Heat Transfer Loads Calculation Sheet located in Appendix A one will see that the heating load and cooling load are almost the same. During the winter the atrium is cold and drafty. There is no way to close off the ventilation outlets/inlets and the uninsulated concrete floor is cold. The floor slab heat transfer is significant in another way. A calculation of the Mean Radiant Temperature Tmr as shown in Appendix A shows that when the outdoor air temperature is 84°F, the Tmr is 93°F with the floor at 84°F. The Tmr is 86°F if the floor is cooled to 70°F. Obviously there is a problem with the floor influencing the atriums interior conditions.

DESIGN CHANGE REQUEST

The atrium was supposed to be conditioned by evaporative cooling and now it appears to be conditioned by an evaporative humidifier. How did this happen? There was a design change request to relocate the misting nozzles from the north side of the atrium to the south side. The architect did not want to relocate the outside air inlet to the atrium's south side, adjacent to the misting nozzles. Please review the airflow schematics shown below in Figure 1. The original airflow schematic shows the air movement in the atrium to have clearly defined loop characteristics whereas loop characteristics in the existing airflow schematic are not clearly defined.

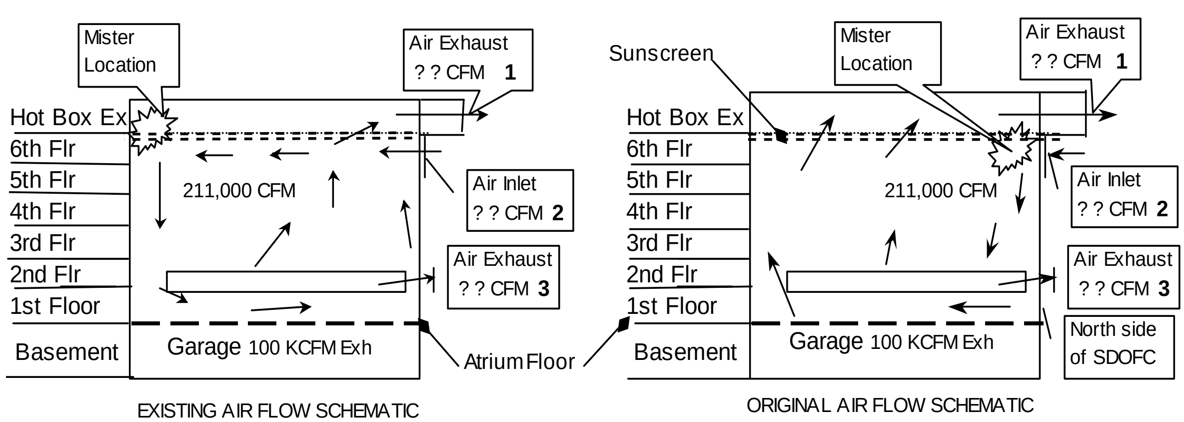

Figure 1: The Atrium's Existing and Original Air Flow Schematics

Design Development Documents

The following are 4 relevant design development documents for the atrium:

1. Ove Arup & Partners Consulting Engineers Final Report: May 1996
2. The Passive Solar Industries Council review: June 1996
3. NREL review: November 1995
4. Independent Computational Fluid Dynamics Simulation: August 1996

The review documents are included in Appendix B of this report.

The Ove Arup Final Report presents and defends its concepts with Computational Fluid Dynamic CFD simulations and other arguments. The Final Report reference's the Fanger Comfort Index, yet does not calculate the Mean Radiant Temperature Tmr. The CFD's modeled the balcony "spill air flow". This spill airflow is ineffective in cooling the balconies. The air is exhausted through the atrium and the airflow pattern does not direct the air across the balconies, instead the air flows downward at the face of balcony/atrium interface. It lacks sufficient volume and flow velocity to create an air curtain to prevent the atrium environment from intruding into the balconies. From my experience air behaves like a young child. It has to be directed and guided so that it does not stray. Air just won't do what I say. Ove Arup's model assumed that the whole width of the entrance doors at the east façade is open during the summer. Their arguments have been shown by reviews and reality to be unsound.

The "spill air" is said to be energy conserving because office building HVAC systems need to exhaust air in order to bring in fresh air for ventilation. The spill air could satisfy the courtrooms/office exhaust requirements. This is an incorrect assumption. Reviewing the construction drawings reveals that there is over 81,000 cfm exhausted from the courtrooms/office rooftop exhaust fans. This represents enough makeup air going to the respective HVAC systems for 4,000 people.

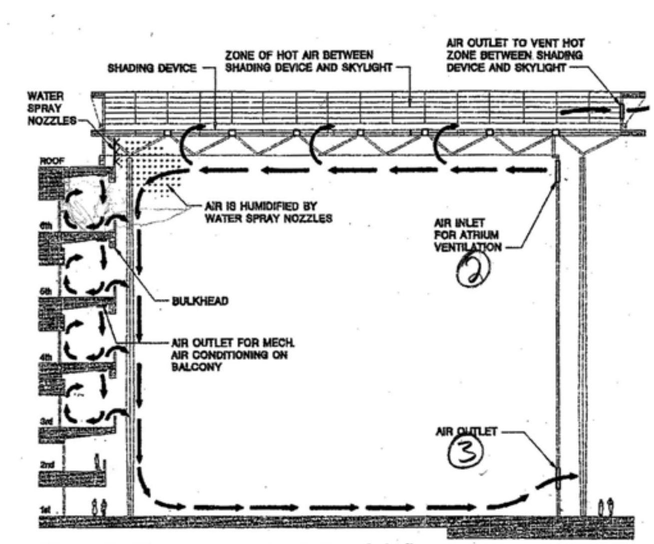

Figure 10: Diagrammatic description of air flow.

- The instantaneous air flow thru the outlet vent is 201,305 cfm which is close to my previously calculated value that correlates ASHRAE evaporation of water to air flow.
- The upper outlet vent (2) has a free area of 1076 sq. ft.
- Face velocity of this vent is 201,305/1076 or 190 FPM. A doable value
- The Lower outlet vent (3) is anticipated to exhaust the majority of the air, negating natural buoyancy affects

Figure 2: Ove Arup flow schematic

The atrium is not performing as shown in Figure 2: Ove Arup flow Schematic. Even in mild weather with the outdoor air temperature at 84°F db, and 57°F wb, the misters are shutting down on high humidity, not temperature.

Ove Arup and Partners developed a CFD model diagram of the airflow in the Atrium, and is included in Appendix B. The diagram shows no influence to the air flow arrows by the hot Atrium floor. The CFD simulation output diagram became the basis for their flow schematic.

The following review comments are from the Passive Solar Industries Council:

1. They agreed that moving the misters south was a sound idea with one exception.
    a. That exception was, to move the air inlet to the south.
2. The north ventilation air outlet should be protected from north winds.
3. The sunscreen louvers should be selected with a high reflectivity/Low-Emissive coating.
4. The ground floor mean radiant temperature should be evaluated.
5. Design a way to prevent hot air above the shading devices along the south side from being entrained into the air stream flowing into the misters.
6. The atrium should be monitored to ensure its performance.

The NREL review was made before the release of the Final Report. They suggested to:

1. Provide backup equipment to condition the atrium during July and August,
    a. Use exhaust fans to ensure adequate air flow.
    b. Use even more spill air than presently assigned.
1. Incorporate a cool tower concept into the atrium design, similar to the NPS Zion Visitor Center, UT. See Appendix B for the NREL concept sketch.
2. Investigate the potential for discomfort from the radiant heat emanating from the sunscreen.
3. Investigate how the "buoyancy in the atrium (stack affect) is somewhat confused by competing forces.
4. Add glazing to the 4th and 5th floor balconies to isolate the balconies from the atrium environment.
5. See E-Source Cooling Manual for more details

The Independent CFD simulation review differed from the Ove Arup simulation. This consultant used the Fluent CFD simulation program. The atrium floor was considered to be adiabatic: no energy transfer, not hotter nor colder than the atrium. The model set the outside air OSA temperature to be 122°F. The following results were in conflict with Ove Arup's

1. The lower vent became an inlet not an exhaust outlet
2. The balconies and the floor temperature was 63°F with OSA at 122°F.
3. The hottest spot was above the sunscreen near the north outlet at 176°F. The independent CFD simulators comments were:
4. "It appears that the mister has a small effect on the air temperatures in the atrium."
5. "The spill air from the balconies is the main means of keeping the floor area cool."
6. "Relocating the upper inlet to the south clearly shows the influence of the air inflow and eliminates hot stagnant regions in the atrium."
7. "Atrium ventilation is driven by small buoyancy forces and the wind influence would be significant and should be studied."

THE ATRIUM'S FUTURE

What can be done for the environment in the atrium now that it is built and there have been three summers of brutal conditions inside the space? The following is a list of some concepts:

1. Determine if the misters are the healthiest moisture source
2. Place the air inlet and moisture source adjacent to one another
3. Reduce the diffusion function effects.
4. Provide a method to shutdown all of the exterior wall openings in order to:
    a. Allow the smoke detection system to operate without nuisance alarms.
    b. Reduce winter drafts and allow the sunscreen to passively heat the building.
    c. Protect the interior from dust storms
5. Insulate the atrium floor
6. Rearrange balcony spill air to:
    a. Wash cool air across the balconies
    b. Obtain the air from within the atrium space/balconies and do not use the courtroom/Office space return air, thereby reducing the makeup air load on the AC refrigeration system.
7. Resolve the influence of the sunscreen on the mean radiant temperature
8. Provide shade sails within the atrium to control the sun and air currents
9. Commission the Atrium's HVAC systems, including a complete air and water test and balance report.
10. Introduce evapotranspiration by growing large plants.

REFERENCES

Fay C. McQuiston, P.E., Jeffrey D, Spitler P.E.. (1992) *ASHRAE Cooling and Heating Load Calculation Manual, 2nd Edition*, American Society of Heating, Refrigerating and Air Conditioning Engineers, INC.

ASHRAE. (2000) *Minimizing the Risk of Legionellosis Associated with Building Water Systems*. ASHRAE Guideline 12-2000 ASHRAE STANDARD, American Society of Heating, Refrigerating and Air Conditioning Engineers, INC.