Domed Stadium Air-Conditioning Design

▶ BY I.A. NAMAN, P.E., FELLOW/LIFE MEMBER ASHRAE ▶ REPRINTED FROM ASHRAE JOURNAL, AUGUST 1966

This paper will discuss methods used to solve the problems related to air conditioning the Harris County Domed Stadium. Specifically, the problems arose as a result of the size of the building, which is larger and greatly different from any other that has ever been air conditioned, and thus created design problems not experienced previously. The engineers in this case were embarking on a project of unknown problems in unknown areas. As the work began to develop, the architects first inquired as to whether the proposed building was practical and feasible to air condition. To form a better conception of the physical relationships of the space, the following will be helpful: The clear height of the roof at the center is about 212 ft above the playing field and the diameter of the circular building is about 640 ft at the point from which air is distributed. The overall area enclosed is some 9½ acres. Seating is provided for 56,000 for football.

There were a number of factors that had to be considered in the feasibility study, including, first, the roof design. This was related to the ability to grow grass inside the stadium, the acoustics, the cooling load, and the problems of heating such a space. The second major factor to be considered concerned the air to be circulated. The questions that occurred to us were as follows:

1. Is the quantity of air required for cooling and heating within reasonable limits for practical distribution?
2. What about the feeling of comfort related to this amount of air circulation?
3. How can the air be distributed over so large an area without extending ductwork to areas where obstructions could not be permitted?
4. Will the noise of distributing the air be excessive?

The next major consideration concerned the problem of the smoke

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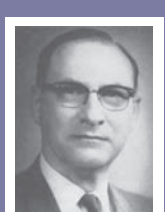


Mr. Naman is the founder of I.A. Naman + Associates, Inc., a consulting engineering firm located in Houston. Mr. Naman opened the firm in 1947 and built it into one of the largest engineering firms in Houston. One of his signature accomplishments was designing the air-conditioning system for the Houston Astrodome in the 1960s.

Mr. Naman graduated from Rice University with a degree in mechanical engineering and received his master's in mechanical engineering from the University of Illinois.

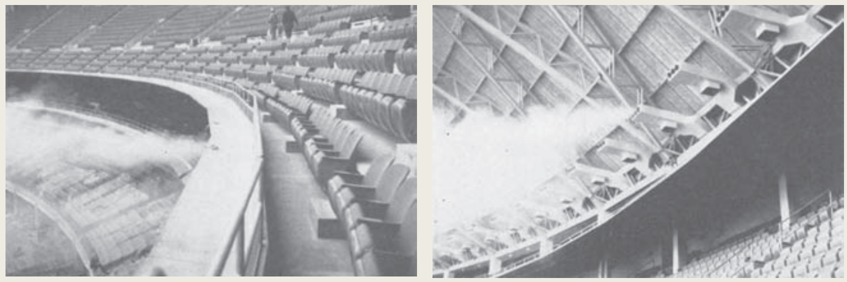
He has served on the board of Houston Industries, as a guest lecturer at Harvard University and Massachusetts Institute of Technology, as a teacher at the University of Houston and Rice University, and in leadership roles in technical societies. He is an ASHRAE Fellow and Life Member and a Life Member of the National Society of Professional Engineers.

Mr. Naman, now 91, enjoys traveling the world, including a world cruise taken last year. He resides part-time in Houston and part-time at his ranch in Milano, Texas.

cloud. There is a seeing distance of about 540 ft, as a maximum, from which the spectators would be able to see a football clearly.

Having observed the smoke cloud that occurs in open air stadiums when viewed at night over the crowd, when floodlights make the smoke particularly visible, it was realized that tobacco smoke might possibly present a real problem. If it were to be a problem, there was a question as to what the solution might be, and more than this, how it could be examined to begin with.

▶ FIG. 1 Smoke tests were conducted in the stadium to determine acceptable limit of smoke cloud.



Another matter which was of particular interest in the feasibility question was in regard to possible "weather." An experience had been reported previously regarding large dirigible hangars, where unusual weather conditions were reported to have resulted in rainfall inside the hangar, even though it was not raining outside. There was speculation that we might have such a situation in the stadium where fog, haze, self-generated turbulence in the nature of a tornado, cloud formations or even rain, might conceivably be experienced. Was this something which really could happen or was it only a fear with no real basis?

The next question concerned the method of temperature control. How could the temperature be controlled in so large an area, with particular emphasis on location of thermostats, the type of control automation required, and the type of air systems required to obtain proper temperature control. There was some concern that temperature sensing would be difficult in the seating areas at locations where it would be meaningful. There might be some question as to the particular system from which the air finally reached some specific point. That is, we might find that, due to turbulence, the air in a given area was not always coming from the same air handling system. Further, with the extreme height involved, stratification could be particularly serious, especially in the winter, and there was a question as to whether this could be avoided.

In arriving at solutions, each of the problems was given careful consideration and answers were obtained either by theoretical analysis, experimentation or both. In the roof design, grass-growing problems had to be examined and experiments performed to provide data on such items as:

1. The amount of light required for growth in the summer.
2. The amount of light required for keeping the grass alive in the winter.
3. The effect of temperature variations on the grass and the effect of changes in humidity.
4. The kind of grass best suited for the application.

The latter, in turn, involved the ability to grow the grass outdoors in the Houston area as well as its ability to propagate properly under the limited light and controlled conditions inside.

The acoustical problem was studied, and it was determined that approximately 50% of the roof area must be devoted to sound-absorbing materials. This limited the light-admitting areas to those not acoustically treated. In studying the roof problem it was realized that the amount of light required for the grass had to be held at a minimum, since this also adds to the cooling load. The design of the light admitting panels would also determine the heating load as well as affect the stratification problem. The solutions to the various matters involved in the roof design took place in several steps. In the first, there was an initial consultation with a physicist regarding the amount of light, in foot-candle hours, that might be anticipated from the area of the roof available for admitting light.

Second, a preliminary calculation of the cooling load was required to prepare early cost estimates and indicate air handling requirements.

Third, a search of literature was made, relating to the smoke problem and the planning of proper tests.

Fourth, research was initiated into air distribution in a large space.

Fifth, an analysis was made of the thermodynamics and psychrometrics of the possible weather problem.

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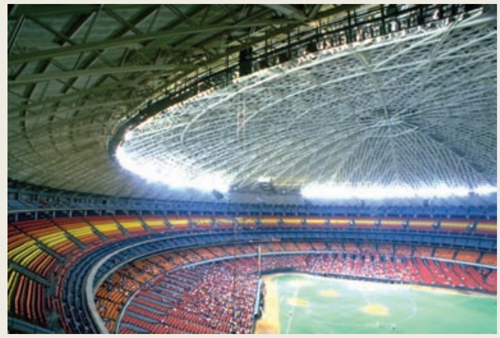
Sixth, an analysis of the possible air motion patterns and the manner in which these could affect thermostat operation was studied. This led to a control design which permitted manual instead of automatic setting of discharge temperature, if it became necessary, as well as the ability to control any area by any selected thermostat, regardless of location, depending on air motion pattern. Parenthetically, the very early determinations of cooling load, air handling volume requirements, smoke cloud control and air distribution methods were surprisingly close to the final calculations and arrangements and to the actual loads experienced.

All preliminary evaluations showed the project to be feasible, and the architects were so advised, but many areas of doubt remained, requiring further analysis and perhaps experimentation. After the architects were given approval to proceed with preparation of working drawings, each of the problems was separately researched, solutions were developed and refined and each interrelated factor was likewise developed and refined. The development of detailed solutions is of interest and will be discussed.

The roof design, with light-admitting panels, progressed slowly and the cooling load, together with associated air distribution requirements, could not be established finally until this was settled. It took two years. The particular matter which took the greatest amount of time was the determination of light requirements for the grass. This alone required one and a half years of research, even to learn the amount of light required for the various grasses and to choose a grass which could satisfactorily be used.

The economics of the roof structure design and light panels were another major research problem. Many methods were examined to limit the light and heat in summer and to increase to a maximum the amount of light in the winter. The consideration here was of course the fact that the position of the sun varies greatly from summer to winter. Houston is located at 30 deg north latitude and in June the sun is almost directly overhead at noon. In December it does not rise past 37 deg above the horizon and, as can be readily seen, the amount of light admitted into the space in June would tend to be far greater than that in December. Hence, if the light available in December were made adequate for the survival of the grass, that in June would be far in excess of the minimum requirements and would greatly increase the cooling load. Thus, a means of limiting the excess light and heat in the summer was of particular interest, but was never achieved within economic limits.

▶ FIG. 2 Houston Astrodome.



Another interesting matter regarding the roof was brought out during wind tunnel tests of scale models of the proposed roof. It was found that during periods of high wind, the shape of the roof was such that the wind would be deflected in a manner to cause a negative pressure at the center of the dome. This would cause a decrease of pressure inside the stadium, with respect to the outdoors, because of the large exhaust openings that were proposed to be located at the very top center of the dome. This lowered pressure within would prevent the doors from being opened (since they must open out, by Code) and people could not get out of the building during such a high wind. Our solution was to provide emergency switches at all main exit doors, so that they could be operated to close the dampers in the exhaust openings in the event of an emergency.

The tobacco smoke problem was of major concern. Fortunately research confirmed, the only published data that we were able to discover, that on Madison Square Garden. Calculations based on the previous work indicated a necessity for accepting a level of smoke that would be termed "commercially acceptable."

It was impractical to try to eliminate the smoke cloud entirely. Further, economics dictated the use of air reclamation by means of electrostatic filters and activated carbon. In choosing the acceptable limit of smoke cloud, a simple experiment was arranged to give simulated visual conditions by the use of a glass box, permitting us to view a color movie of a baseball game through smoke introduced into the box. The smoke density was carefully controlled and properly instrumented to give an accurate visual representation of the effect of various smoke densities. The greatest density that was considered acceptable was chosen.

A total of about 2 ½ million cfm of air is circulated in the stadium, as determined by the smoke elimination prob-

A RETROSPECTIVE FROM 2009 ON I.A. NAMAN'S FIRST OF ITS KIND DOMED STADIUM

Reading the article written by I.A. Naman, P.E., Fellow/Life Member ASHRAE, on the factors considered in the feasibility study and subsequent design of the Houston Astrodome, formerly the Harris County Domed Stadium, brings back memories of countless baseball and football games I was fortunate to attend there over some forty years.

It is a tribute to Mr. Naman and all involved in the design and construction of this historic facility that not once during my many hours spent inside the Astrodome did I feel anything but comfortable. Temperature, humidity, smoke control (when smoking was allowed) and the acoustics of the facility were all controlled so well that, after getting past the awe of seeing the facility for the first time, the environment could be taken for granted.

Most are probably aware of a problem that did surface that was outside the scope of a mechanical, electrical and plumbing engineer. Since the roof was designed to allow in the light necessary to grow grass, there was a glare on sunny days that prevented the fielders in baseball games from seeing baseballs hit high in the air. To overcome this problem, the individual roof panels were painted with a coating. While this solved the fielding problem, growing grass inside became impossible.

Much to the chagrin of athletic purists, the Monsanto Company had invented a grass substitute sold under the name Chemgrass. It was renamed Astroturf® after its use in the dome in 1966. Astroturf is now used regularly in professional and high school stadiums across the country. From an engineering standpoint, reflecting light rather than having it pass through the roof over 9.5 acres probably had a substantial reduction in the cooling load, but added to the heating load.

In 2002, Reliant Stadium, a new retractable-roofed stadium, was built adjacent to the aging Astrodome within Reliant Park. The historic facility is now rarely used and only hosts occasional concerts and high school football games and currently has no major tenants. In its failed bid to host the 2012 Olympic Games, Houston included renovating the Astrodome for use as a main stadium. The dome also garnered widespread attention in the aftermath of Hurricane Katrina in 2005 when thousands of evacuees from New Orleans were housed there.

The Astrodome was a first of its kind. Thanks to Mr. Naman and the design team for the Astrodome, the design of the many indoor stadia that followed was made simpler by the success of this pioneer.

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lem and not by the cooling-heating load alone, although they happened to agree very closely. Ten percent outside air, approximately 250,000 cfm, was required to limit the carbon dioxide build-up and all of the air had to be filtered electrostatically in order to achieve the limit of smoke density desired. Eye irritation due to tobacco smoke was limited by treating 627,000 cfm with activated carbon.

The possible "weather" problem inside was virtually eliminated by the realization that the space must be kept under constant temperature control at all times, summer and winter. However, condensation on cold surfaces in winter was the only serious matter that was anticipated after careful analysis. Other possibilities that were imagined that could develop were not found to be consistent with meteorological factors involved.

Temperature controls were of particular interest. More was involved than just the problem of thermostat location already mentioned. When the playing field itself is to be used for seating perhaps 10,000 people, how could this be handled by perimeter thermostats? The large field area obviously could not be adequately controlled from the perimeter and a radio thermostat was developed that would control any of the main air handling units which may readily be switched to it. The thermostat can be carried onto the playing field and located at the speaker's stand or at any other convenient spot.

Control problems must be quickly recognized during an event and any equipment failure corrected. Only an automated, logging arrangement with alarms for off-temperature indication could quickly locate the point of trouble and help to determine its source. Electrostatic air filter failures must be alarmed, as well as temperatures, and of course pilot lights should indicate equipment operation. A new development was an ultra violet smoke density meter which continually indicates the smoke cloud.●