

# AIR CONDITIONING AND REFRIGERATION Journal

The magazine of the Indian Society of Heating, Refrigerating and Air Conditioning Engineers

Issue : January-March 2003

## Air Conditioning of Auditoriums

**By M. H. Lulla**

*Consultant, Chennai*

*A 1966 engineering graduate from Annamalai University, he worked for 8 years with a contracting company before setting up practice as an HVAC consultant. Has designed AC systems for over 40 auditoriums. Teaches at the Anna University School of Architecture and is an ISHRAE member.*

The movie theatre industry was the first to recognize and realize the benefits of comfort air conditioning. Five decades back, in India, if a common man wanted to experience the comfort of air conditioning the only way to satisfy this desire was to buy a ticket for a matinee show in the city. Cities as big as Madras (Chennai now) had only one or two air conditioned theatres – as a matter of fact one of the earliest air conditioned theatres in the city “Minerva” is still cooled by its original, 50 year old air conditioning system.

Air conditioned movie theatres and auditoriums are characterized by several special considerations in their system design which include:

- Cooling load calculation
- System type determination
- Air distribution
- Foyer air conditioning

### **Load calculation considerations.**

Factors which influence the load calculations to a greater extent than, normally are:-

**Occupancy.** The single largest factor in such applications is the heat load from people. What should be the design occupancy of an auditorium? In performance auditoriums which include halls used for live shows, conferences and meetings, the seating capacity may not be the design occupancy, since the occupancy becomes a function of the usage pattern. In the auditoriums of educational institutions, it could range from almost daily to, a low of, just 15 to 20 days in a year. For the former usage pattern, occupancy may vary from virtually 0 to 100% whereas, for the latter pattern of usage, virtually 100% occupancy is to be expected. Maximum possible seating capacity should be used as a starting point and provision then made to allow for standing (in aisles) if permitted by local fire codes. On this number a designer can then apply a diversity factor. A diversity of 0.9 is generally safe.

In movie theatres in the big cities which have more than three daily shows, houseful shows during weekends are to be expected, hence full seating capacity is to be taken as the load factor. With evening shows also being full and outside relative humidity being higher in the evening, generally the peak load occurs at 8 p.m. (Auditoriums for movies are unique as they do not have a stage, and design occupancy is generally – the seating capacity).

**Ventilation.** 5 cfm / person is an often repeated benchmark for fresh air. The figure has been valid for, “no smoking” auditoriums for a long time. The latest ASHRAE codes which are driven by IAQ considerations call for 15 cfm / person. If one were to consider that most auditoriums are never full all the time then one can take the liberty of saying that 5 cfm / person based on the full seating capacity does give acceptable IAQ most of the time. This indication must not be read as suggesting that ASHRAE figures need not be implemented. For prestigious auditoriums designed to international standards it is imperative to follow ASHRAE standards.

If the 15 cfm / person figure is adopted and the fresh air quantity works out to a figure greater than 2 air changes / hour, then it is advisable to positively exhaust the air quantity in excess of 1½ air changes / hour and use it for heat recovery from the fresh air intake to the air conditioning system in order to conserve energy.

It is also advisable to flush the auditorium with 100% fresh air, periodically. To make this possible, fresh air intakes must be oversized. Flushing can be done at off-peak times or at times when outside ambient conditions are low.

**Solar and Transmission gain.** The fabric gain in an auditorium is mostly from the sun-exposed roof since few auditoriums have windows for natural light and hence solar gain is virtually out of reckoning. Sunexposed roofs must be insulated – a minimum of 3” thick, foil-faced fibreglass may be applied to get a value smaller than 0.1 Btu/hour/sq. ft/°F. The attic space, if not used as a return air plenum, must be sealed and left “hot and stratified”. (This presupposes that the insulation is on the main sun-exposed roof membrane)

For acoustical purposes, most wall areas are insulated and panelled which help to improve the thermal value of the wall and reduce the heat flow into the structure – the total reduction due to this treatment does not appreciably alter the total heat load of the auditorium.

**Stratification.** While calculating heat loads, the whole auditorium is reckoned as a single zone. On the other hand, in applications where the auditoriums are taller than 9 m and use side-wall grilles one can appreciate that a large volume of the auditorium does not participate in the air movement, and tends to become a stratified hot pocket. A designer can use this to select a smaller air conditioning system in which the plant capacity can be safely reduced by 40% to 50% of the heat load of the hot stratified pocket. (Generally the volume, 1.5m higher than the side wall grille up to the roof can be considered as the stratified zone for giving credit to the heat load – see calculations in the example)

**Example**

To help explain the above factors it would be interesting to see them applied on a model. Take a typical 1000 seater hall in an upmarket convention centre. Say, 30m x 30m x 8m high up to the false ceiling with foyers all round and an RCC roof, as in Figure 1, at Chennai for which Outside Design Conditions are - 102° F db / 83° F wb).

**Occupancy** – It would be advisable to take the full seating capacity as the occupancy – a diversity on this is not being taken as the convention centre will have halls of various sizes and chances are that the halls are carefully allotted / used to get full utilization (i.e. they are likely to be “full” always).

**Ventilation** – By virtue of the hall being upmarket it will be imperative to provide for FA as per international standards (15 cfm / person). The 15 cfm per person works out to over 3 a/c per hour – in such cases one can easily consider exhausting FA, in excess of 1½ a/c per hour, positively through a heat pipe exchanger or energy wheel and save up to:-

$$\frac{8700 \times 17.2 \times 4.5 \times 0.7}{12000} = 40 \text{ ton, where}$$

- 1 a/c / hour = 4280 cfm
- FA @ 15 cfm / person = 15000 cfm
- Exhaust air = 15000 – (1.5 x 4250) = 8700
- 17.2 is the enthalpy difference between outside air and inside air in Chennai (i.e. 47-29.8)
- 4.5 is the standard heat load factor and 0.7 is the assumed efficiency of the energy recovery system.

**Roof heat gain** – Must be controlled by standard levels of insulation (at least 3” fibreglass on sun exposed roof)

**Stratification** – If the hall is to have an air distribution scheme as in Figure 3, then, due to stratification of the hot air near the roof, one may reduce 50% of the heat load incident, say, 1.5 m above grille level i.e. above 6.5 m level. This can be estimated as under :

$$\begin{aligned} \text{Roof gain } 30 \times 30 \times 10.76 \times 0.1 \times 55 &= 53,262 \\ \text{Wall gain } 30 \times 4 \times 1.5 \times 0.36 \times 20 &= 1,296 \\ \text{Sub Total} &= \underline{54,558} \text{ or } \approx 5 \text{ ton} \end{aligned}$$

The total load of the auditorium may be reduced by 50% of this as credit for stratification, say by 3 ton.

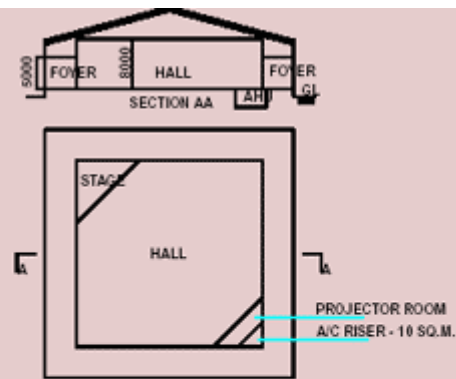


Figure 1 : Plan of A 1000 Seater Auditorium

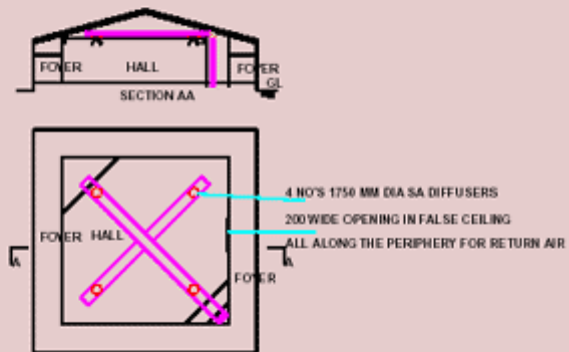


Figure 2 : Plan of hall ceiling distribution for cooling (Read with Figure 1)

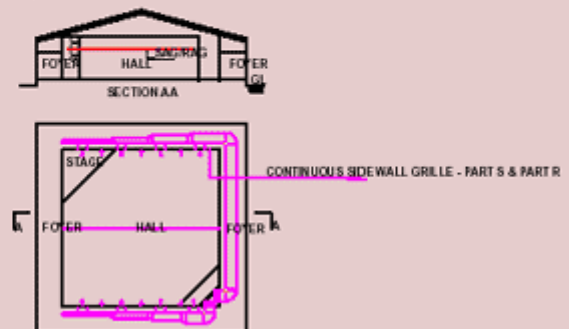


Figure 3 : Plan of hall with side wall grille for cooling (Read with Figure 1)

**Storage Effect.** In general, the mass of the structural elements and furnishings per person is higher than in most other applications. This is an opportunity to use storage effect to advantage – to downsize the air conditioning plant.

Based on the above factors the pulldown load is also very high. For plants which are used infrequently (less than 3 hours at a time) one can select a plant 10% smaller than design and meet the pulldown needs by operating the plant for 2 hours before usage and lower the temperature to say 1.5°C below design. During usage, the operating conditions are restored and the precooled mass absorbs some of the heat load.

**Inside Conditions.** It is normal to aim at holding inside conditions to 23/24°C and RH between 40% and 60%. With good wide seats, at 900 mm centre lines, which keep the occupants far apart and with ceiling heights greater than 7.5 m it is often surprising to note that 25°C is also not uncomfortable. This is perhaps, because the influence of the occupants, around a subject by way of radiation temperature, gets diluted. (A person's skin temperature is close to 35°C as against a brick wall which may be at 25°C.

**Outside Design Conditions.** The outside conditions used in the heat load should be taken at the time of the day when the peak load occurs. For movie houses featuring noon shows and matinee shows, the general outside design conditions used commonly become applicable. For performance auditoriums – with one show a day – generally the 8 p.m. load is the peak load.

**Heat Load Calculations.** Some handbooks give simplified curves and procedures for estimating heat loads of the auditorium. One only needs to know outside design conditions, numbers of seats, cfm / person and the inside conditions. This data is keyed into a set of curves to get the auditorium heat load. The heat load for the foyer and other spaces cannot be calculated by this method. These curves are based on conditions in the US where generally the time between shows is larger than in India, due to which benefits of “fresh air flushing” and storage get lost.

## System Determination

With the cooling load determined one has a fix on the plant capacity. The plant capacity can be met by various types of systems:

- Central chilled water system
- Central DX system
- Package equipment system
- Storage cooling system

**Central Chilled Water Systems.** In this case the major advantage is that the chilled water plant is remote located (with only AHUs being close to the hall). This feature reduces noise transmission into the hall, and allows one to centralize the services of the whole complex. The chilled water system may be air-cooled or water-cooled. This system is more expensive.

Prime candidates for using such systems would be convention centres like the Vigyan Bhavan at Delhi or the Raffles Convention Centre at Singapore – structures which house such facilities are massive, with less external walling when compared to internal floor space. Such structures have internal service cores which tend to use only small areas – AHU rooms are also located hereabouts, by virtue of these being small, land locked, away from external walls – making them eminently suitable for a chilled water system.

**Central DX Systems.** This type of system is well suited for such applications as the auditorium is basically a single zone. By locating the equipment properly and providing for

the usual acoustic attenuation, the noise of the plant can be “kept” within limits. For large auditoriums, it is normal to use multiple DX systems with each system being, say, a minimum 60 tons. Each system will need to have two independent refrigeration circuits and each system may have a common AHU with two cooling coils or ideally two AHUs with a cooling coil each. Generally these systems may have to be water cooled – so that the heat rejection equipment like cooling towers, can be remote located from the plant. These systems are not as expensive as the chilled water system, as they do away with the need of chillers, chiller pumps and chilled water piping.

Prime candidates for using such systems are very large auditoriums, when built in exclusive buildings. This can be seen in the example of the APTDC auditorium detailed later – where 4 x 80 ton systems cool the auditorium and each 80 ton system has 2 x 40 ton independent refrigeration circuits. Large indoor auditoriums calling for, say, 1500 tons of cooling could be economically cooled with 10 x 150 ton plants each with 2 x 75 ton DX circuits.

**Packaged Equipment Systems.** With large capacity, reliable, factorymade equipment being freely available at unmatched costs, one can use such equipment also for this application. Multiple package units / ductable splits can be used well. Factory-made comfort equipment – with cooling coils which are only 3 rows deep – theoretically does not meet the “adp” needs of the application, but in practice such equipment has been used with the ensuing, higher relative humidity never posing any serious problem. These systems are generally the most economical, particularly, if used properly with limited ducts. Use of multiple units can be made to bring in an additional advantage of grouping them together to form “zones” – say one set of equipment for the stage, another set for the front half, yet another set for the rear half, etc. With this kind of zoning one can operate the stage plant only during rehearsals, likewise the stage plant and the front half area plant may be run to cool only a partially-filled auditorium.

Prime candidates for using such systems are small 30 / 40 ton capacity halls used by educational institutions. This, of course, gets stretched, to such systems being used even for large assembly areas like marriage halls, community centres, etc. Generally one feels comfortable using such systems for halls which do not have a continued, long-duration occupancy, such as marriage halls.

**Storage Cooling Systems.** On specific applications, such as temple halls, churches etc. where one needs cooling only for, say, three hours a day and even that, only once a week, storage systems can be used. Thermal storage systems can be as simple as the “ice

storage” ones, or as sophisticated as “eutectic salt in custom containers”. Costs will dictate the use of low-end systems, but with ice systems using direct ice melt, one may need to have an AHU with a larger-than-normal coil bypass area. (Simple ice melt systems are the ones where, as in dairy milk coolers – ice is formed on bare pipe coils, in the “a/c off” mode and in the “a/c on” mode the ice melts and ice water at 0°C is pumped to the AHUs. Since this water is very cold, the dehumidified cfm is reduced and is nearly half of the normal design cfm. The cold air from the AHUs is discharged very carefully into the unoccupied high zones of the auditorium, through high-induction outlets and ceiling fans below the outlets mix this with room air and blow it across the occupants. These systems are very cost-effective for applications which need cooling for say 3 to 4 hours only in a week.

## Air distribution

With a given set of equipment and layout and a fixed seating arrangement the air distribution system should aim at the following:-

**Draft.** There should not be any occupant areas which get greater than 25 fpm air movement – pockets of “drafty seats” will render maintenance of comfort conditions impossible.

**Direction of air flow.** Over the anatomy of a person in the seats should ideally be on the face and neither on the nape of his neck nor his ankles.

**Acoustics.** The SA and RA outlets should be kept as distant from the mike as possible and they should also be as far away as possible from the ears of the audience. In such detailing – the source of noise and the receiver of noise are rendered distant from one another.

**Duct velocities.** Ideally duct velocities at starting points should not exceed 1200 fpm – but if the AHU rooms are not very close to the hall and the first SA point is 20 m away from the AHU discharge, then one can go up to 1500 fpm for performance auditoriums and movie theatres. (Recording stations are totally different and will not permit velocities higher than 1000 fpm). Splitters and sharp fittings in the ducts must be avoided and only plenum fittings used. Ideally dampers in ducts and on the grilles must be omitted and TAB (Testing, Adjusting, Balancing) work effected by using perforated sheets on the collars – these perforated sheets can be fitted on the inside of the main duct by tinkers working on the inside of the main duct (duct sizes are generally very large and permit such movement and usage).

**Stage cooling.** It is not unusual for a stage to have around 500 kW of lighting – the high cfm for the high load is best discharged from air outlets high above the stage. Small 12” diameter collars (preferably without diffusers) are the best form of discharge. The centre lines of these or even smaller diffusers must be, say, a maximum 3 m in both directions. With such a discharge pattern one may have any number of vertical backdrop screens erected but will still have cooling – behind and in front of any screen. The above requirements, when put together for implementation, can lead to very interesting solutions. Some apparent contradictions in the above requirements can be ironed out by simple acoustic treatment, as can be seen from the few examples detailed later.

## Foyer air conditioning

Foyer air conditioning should ideally be effected by an independent system which permits:

**Independent operation.** Foyers may work longer hours or shorter hours than the main auditorium – depending on the nature of use, the auditorium is designed for. This permits diverse usage patterns and finally results in energy-saving by judicious usage.

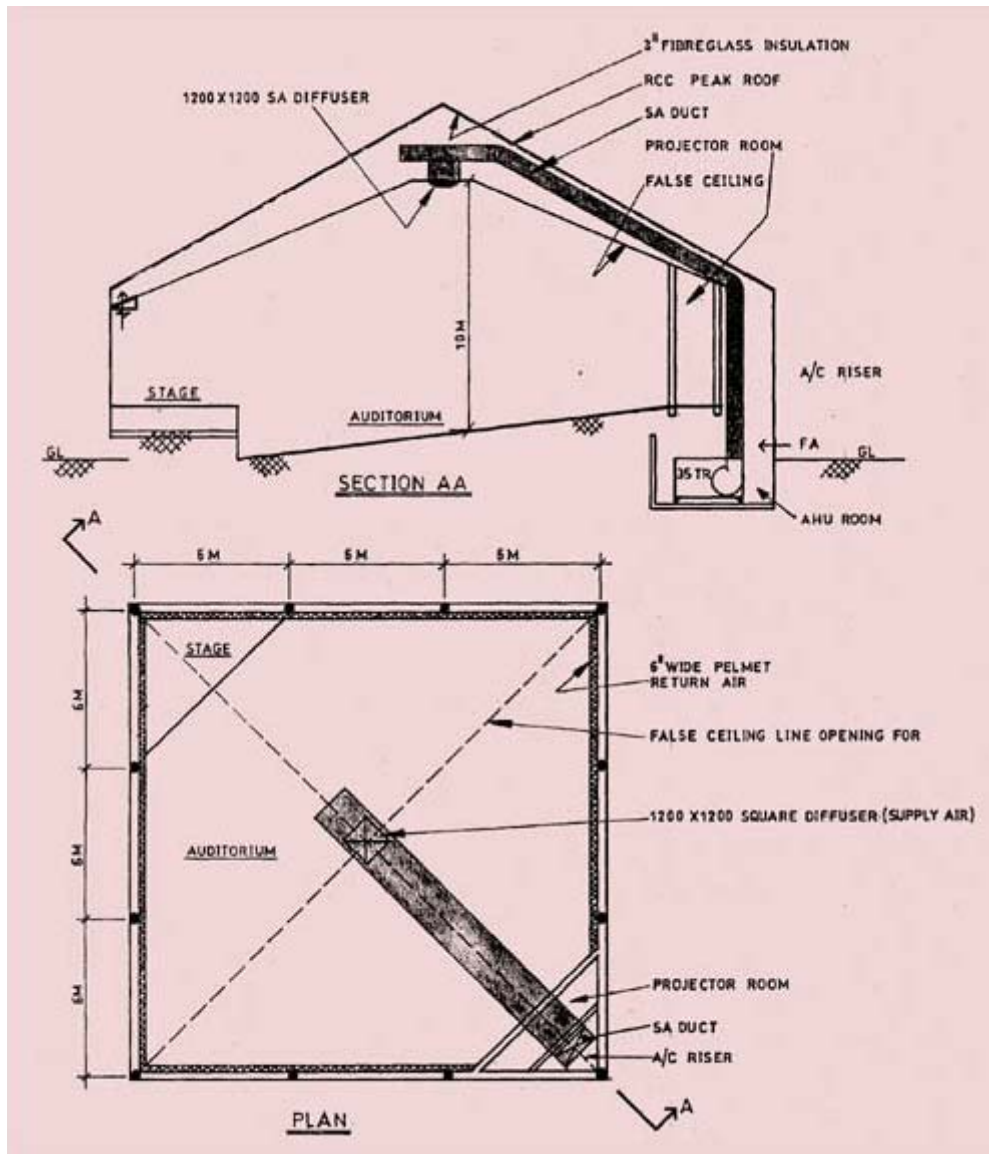
**Cross contamination.** Foyers are generally used for serving food and sometimes allow smoking – separate a/c systems for the foyer restrict cross contaminating the two spaces with odour and this can also be extended to noise control. Separate a/c systems for the two areas ensure greater “privacy” between the two, i.e. the foyer and the hall.

**Safety.** Separate a/c system also automatically compartmentalizes the foyer and the auditorium. This separation brings in an element of safety in case of a fire situation. Foyers in cinema theatres, where usage is restricted to say 15 minutes, every three hours or so – one may just have an exhaust system with plain propeller fans which exhaust, say 70% of the FA taken for the auditorium, through the foyer positively – at points of continued occupancy. Additional local recirculation fans (ceiling fans) can be installed. This detail renders an unconditioned foyer “comfortable”.

## Example 1 - Using a Central Chilled Water System.

A modern auditorium 18m x 18m x 10m high, for 300 people, at the Electronics Technopark needed about 35 tons of cooling – the cooling was integrated with the building’s chilled water system with a 35 ton chilled water AHU. A conventional single-skin AHU with 3 x 18” diameter simple, forward curved fans on a common shaft, was installed in the basement below the projector room. A masonry shaft from the AHU room, rising up through the projector room, permitted the installation of an uninsulated duct

within. This duct rises to the rooftop and just a single 4ft x 4ft square diffuser discharges the entire 35 tons of cooling that is needed for the total space. Return air is collected through openings in the pelmet all around the auditorium at the lintel level (See **Figure 4**).



### Example 2 - Using a Central DX System.

The recently completed APTDC auditorium at Hyderabad uses a DX system for cooling – the auditorium is part of a complex at Shilparaman with air conditioned conference rooms, exhibition halls, dining complexes and showcase areas for arts and crafts – the auditorium is a circular area with an RCC roof. The planning was carried out for a 3000-seat occupancy with large foyers and ancillary spaces. A cooling load of 320 ton was estimated to be met by 4 x 80 ton plants serving separate areas as under:

- 1 x 80 ton plant for the foyers, both on the ground and first floors – (approx 40 ton each) These two multilevel foyers were put on a common plant as both foyers are virtually contiguous with very large connecting stair cases.
- 1 x 80 ton plant for the 1000 odd seats, below the balcony
- 2 x 80 ton plants for the rest of the space viz. the stage, the front portion of the hall and the balcony space.

Un-insulated duct work was installed in masonry risers for air distribution. Duct insulation was confined to:-

- Acoustic insulation for the first 6 m of duct run from the AHU and
- Thermal insulation for the tail ends of the duct.

### **Example 3 - Using Packaged Units.**

A 1000 seating auditorium, as part of a recreation complex, in the Sri Shivasubramaniam Nadar College of Engineering, Kalavakkam – needed 110 tons of cooling. As the college auditorium would work only 15 / 20 days in a year, it was necessary to use simple, reliable equipment. 7x15 ton air-cooled packaged units were installed with the air-cooled condensers installed just outside the AHU room, which was virtually over the stage. The stage has an RCC roof and is part of a multi-storeyed complex which houses all the club rooms etc. The stage space fronts on to a light weight, industrial building structure, which houses the auditorium and foyer. The foyer is not air conditioned and insulated ducts from the AHU room enter the attic space over the false ceiling of the auditorium. A set of 4 diffusers in the middle – high portion of the false ceiling cool about three-fourths of the seats – the balance seats which have a lower false ceiling and are more remote from the centre have small diffusers located, copy book style, to cool these “remote” seats. Return air is collected through a 600 mm wide RA grille in the false ceiling just above the curtain. (See **Figure 5**).

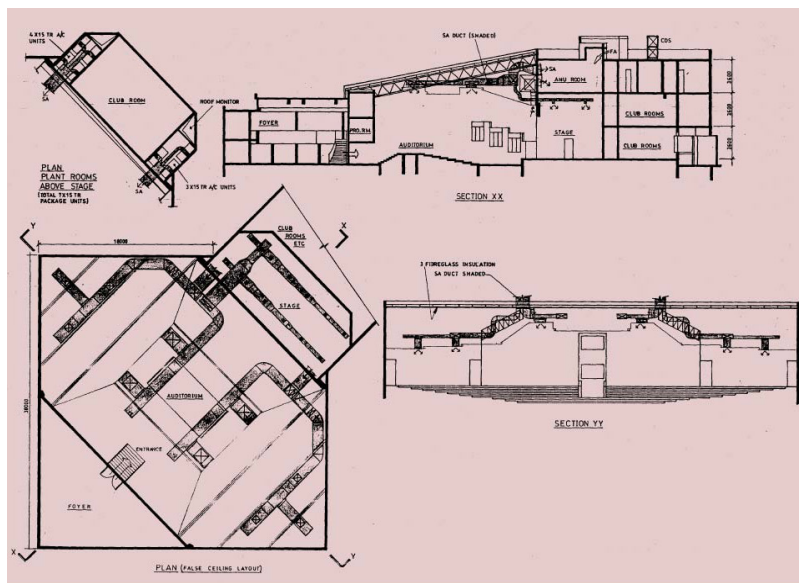


Figure 5 : Sri Shivasubramaniam Nadar College of Engineering, Kalavakkam – 1000 seating size

### Example 4 - Using Ductable Splits.

A 400-seat simple auditorium, is just 28m x 12m. The auditorium located at the MOP Vaishnav College of Women at Chennai, is on the 2<sup>nd</sup> floor and is covered by a light asbestos cement sheet insulated roof. The roof extends down over the corridor as a “lean to roof” to form the foyer along the full length. Simple 7.5 ton air cooled split a/c units are suspended in the corridor and blow air, virtually directly, into the auditorium through a single sidewall grille. An adjacent grille brings back RA to the a/c units and the foyer has a false ceiling and the triangular cross-sectioned volume over the false ceiling acts as a RA plenum. To lengthen the SA duct run from the a/c unit to the SA grille – the unit is made to discharge air, apparently, away from the auditorium, but a couple of bends reverse the air back into the auditorium. The grille mounting height is nearly 4 m and the grille has horizontal front slats with the top one-third slats angled 30° upward, the middle third kept horizontal straight and the lower third angled 30° downward to evenly reach air for the 12m throw. None of the seats are drafty and noise has never been a problem despite the short distance between the a/c unit and the supply air grille. (See **Figure 6**).

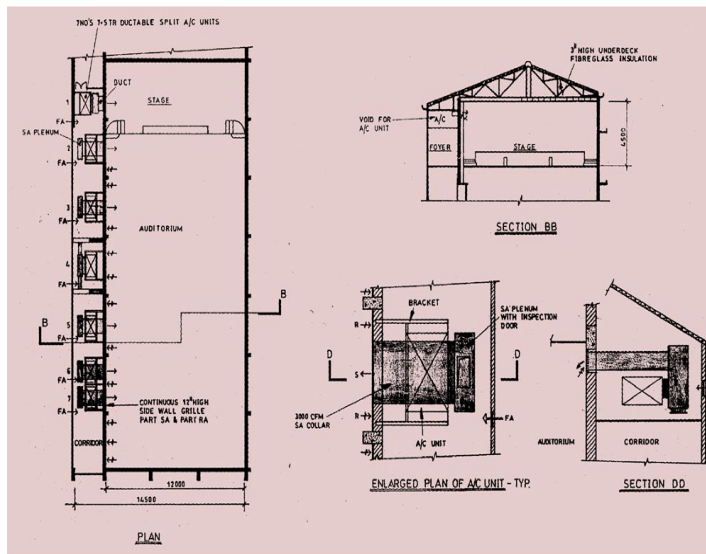


Figure 6 : MOP Vaishnav College for Women, Chennai

## Conclusion (by the Editor)

This article will have served its purpose if it helps young engineers to understand the various factors that must be considered in the design of an air conditioning system for an auditorium, whether it is part of a movie theatre, a concert hall or a school/college.

*ASHRAE Application Handbook* is a very good source of further study and an entire chapter is devoted to air conditioning of *places of assembly*. Engineering catalogues of manufacturers of “Heat exchange wheels” will facilitate selection of such equipment to reduce energy consumption where fresh air quantities are kept in line with ASHRAE ventilation standards. Young engineers are encouraged to constantly strive to reduce energy consumption by studying more recent methods of achieving this by use of CO<sub>2</sub> sensors for fresh air damper control and introduction of Ozone to help reduce fresh air requirements.