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Computational fluid dynamics analysis of HVAC system in auditorium

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Abstract

Computer simulation played a key role in the optimization of a displacement ventilation system in auditorium by helping to reconfigure the locations of the diffusers and the exhausts in order to eliminate unnecessary air flow. Displacement ventilation systems, which locate the air supply on the floor instead of the ceiling, are gaining popularity in North America because they are more efficient and require less energy to maintain a given level of comfort. However, displacement ventilation systems are generally more difficult to design due to several inherent issues like the need to avoid temperature gradients and drafts with the air supply located near the people. In a recent application, these challenges were addressed by simulating a school auditorium using the computational fluid dynamics (CFD) technique to evaluate airflow velocity, pressure, and temperature. The simulation showed the existence of a flow pattern that had both hot, cold spots as well as a stagnant area in the auditorium. The diagnostic information provided by the simulation results made it easy to improve the flow pattern by changing the location of some of the diffusers and exhausts.

Keywords: building energy auditorium, Auditorium energy simulation, HVAC systems

1. Introduction

Throughout the 20th century, trends in HVAC design have been determined largely by technological advances and energy costs. Engineers have always sought to find new ways to ensure occupant comfort, but the level of attention devoted to finding innovative ways to reduce energy use has fluctuated over the last few decades. When energy costs have risen, energy efficiency has become a priority; when they have been low, it has been less of a design driver. This article identifies several trends which are being used to reduce energy use in commercial buildings. The trends to be considered include decoupling of ventilation and heating/cooling, designing systems for optimal efficiency, increased analysis in system design, and total auditorium integration. Consequently one of the main criteria in the redevelopment is to improve the Thermal comfort within the auditorium for both the performers and the audience. Given the constraints of the existing building and systems installed the proposed system was expected to improve the comfort issues that were raised however to assist in providing confidence in the design a Computational Fluid Dynamics (CFD)investigation was undertaken. In addition to general rebalancing, the major proposed change is the reconfiguration of the under floor exhaust to the front stalls area to serve as supply air and the alteration of some high level.

In this paper, we first describe the auditorium and the multi modal of air condition are installed throughout the auditorium. We then build thermal models of the auditorium via system Identification techniques and analyze the quality of the models. To reduce the complexity of the thermal model, we employ spectral clustering methods to group ventilation according to their temperature measurement and correlation. By selecting a suitable air condition from each group, we construct simplified thermal models that can approximate the spatio-temporal thermal dynamics of the large space. Evaluation based on a three-month data trace collected from the auditorium shows that our models can capture the thermal dynamics at sufficient accuracy and spatial granularity. Our modeling approach provides a practical foundation for fine-grained HVAC control design and optimization for large open spaces.

2. Related Works

Displacement ventilation is a unique concept for ventilating Auditorium and supplying conditioned air. It uses the natural buoyancy of warm air to provide improved ventilation and comfort. First developed for industrial buildings, displacement Ventilation now enjoys an increasing market share in many applications throughout the world. Although relatively new to the United States, displacement ventilation has-been in use in Europe, since the 1970s. In a conventional HVAC system, air is supplied at a relatively high velocity towards the ceiling at a temperature about 20^0F below the design temperature. The supply air mixes with the room air to provide a nearly uniform temperature throughout the space. The mixing slows the rate, at which the room air recalculates,

Resulting in relatively low ventilation efficiency. In a displacement ventilation system, on the other hand, supply air is introduced to the space at or near the floor level at a temperature only slightly below the design temperature at a low velocity. The cool, clean air spreads and forms a pool of conditioned air over the floor in the occupied space, displacing the warmer room air. When the cool air meets a heat source, the temperature difference creates a buoyant force and a convection plume is generated. This plume acts as a channel through which warmed and dirty air moves upward to a ceiling area where it exits through the exhaust. Due to entrainment of the surrounding air, the volumetric flow of the plume gets larger as the plume rises. When the flow rate of the plume is equal to that of the supply air, thermal and containment zones form a level or area that distinguish the upper (warm and polluted) and lower (cool and clean) levels of air. This level or area is termed as a stratification level through which there is no flow exchange between lower and upper levels. The warm and contaminated air and contaminants are then exhausted from the space near the ceiling. This stratification is one of the greatest advantages of thermal displacement ventilation systems over conventional mixing type ventilation systems. Cool and clean air is where people need to breathe it and hot, dirty air is at the ceiling being exhausted. In addition to the fact that the displacement ventilation approach improves indoor air quality in the lower level by separating contaminated air from clean air through the stratification, many investigators have noted the advantages of displacement ventilation in lower energy costs. Location of heat source is higher; heat gain from a heat source to the lower level decreases significantly, which results in a reduction of the cooling load in the lower region.

3. System Outline

The auditorium is generally divided into the following major spaces; circle, stage, wings, windows and boxes.

Hvac Total Heat Load Calculation

- Location: Vellore
- Building Area: 2712.977 sq. feet.
- Dbt: 103°F(summer) or 39.4°C
- Wbt: 82°F(summer) or 27°C
- Orientation: stage is towards west
- Latitude: 13.04 °N
- Daily temp.: 18°F or 7.8°C
- U-Overall values of the materials: from ASHRAE standard data book

I. Auditorium Sensible Heat

A1) Solar gain through glass
A2) Solar and Trans gain through walls and roofs.
A3) Trans gain except walls and roof
A4) Infiltration and outside air
A5) Internal heat gain
Sensible heat sub- total =A1+A2+A3+A4+A5
Factor of safety = 10%
Total sensible heat = (A1+A2+A3+A4+A5)*1.10

II. Auditorium Latent Heat

Q1 = infiltration (cfm) *0.68.
Q2 = outside air (cfm) *0.12*0.68.
Q3 = people* latent heat released per person.
Latent total heat = Q1+Q2+Q3.
Factor of safety = 5% [supply duct and leakage losses]
Total latent heat = Q1+Q2+Q3+ (Q1+Q2+Q3)*5%

III. Room Total Heat= Total Sensible + Total Latent

Existing Hvac System

The 3D modeling of base diffuser (exciting model) type of auditorium was created using Autodesk Revit 2015 & CATIA R5 software package. Its included for All views, such as plans, elevations, sections, details, schedules, as well as all design sheets printed for construction documents, are automatically generated based on the model. The Autodesk Revit Architecture software coordinates with two other software packages: Autodesk® Revit® MEP (Mechanical, Electrical, and Plumbing) and Autodesk® Revit® Structure. The exiting model of auditorium major demerits of improper air distribution inside the auditorium also which has consumed maximum rate of energy rate level. The existing system that serves the auditorium comprises six receiving air handling units and six existing spill air/smoke exhaust fans. The system layouts make use of the symmetry about the building axis line, with each being essentially the mirror of the other. The existing supply scheme utilizes 14°C supply air delivered by overhead diffusers, with supplemented by sidewall supply diffusers. The stage is cooled via supply to the wings, and by high-level grilles (above the boxes). Return air to the air-handling units is primarily via sidewall grilles on the stall, circle and balcony levels, supplemented by ceiling return above the stage, through the side walls and under floor return grilles in the lower stalls. The existing system that serves the auditorium comprises six receiving air handling units and six existing spill air/smoke exhaust fans Spill air is exhausted by the smoke exhaust fans withal majority of the air drawn from ceiling level above the stage supplemented by a mid-level wall grille. This arrangement can be seen below in *Figure1 &2*

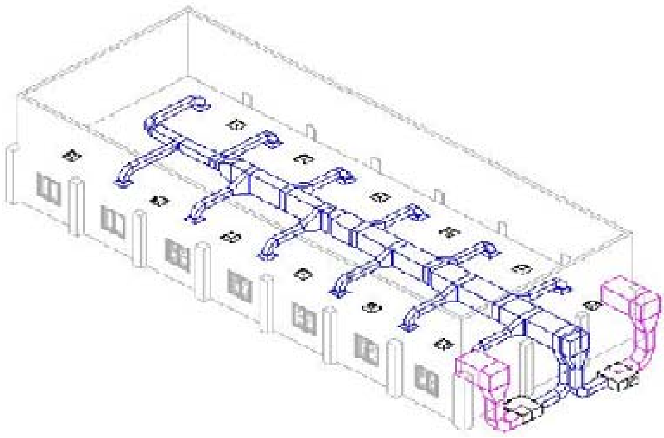


Fig 1: Existing (Diffuser) HVAC system using Revit 2015

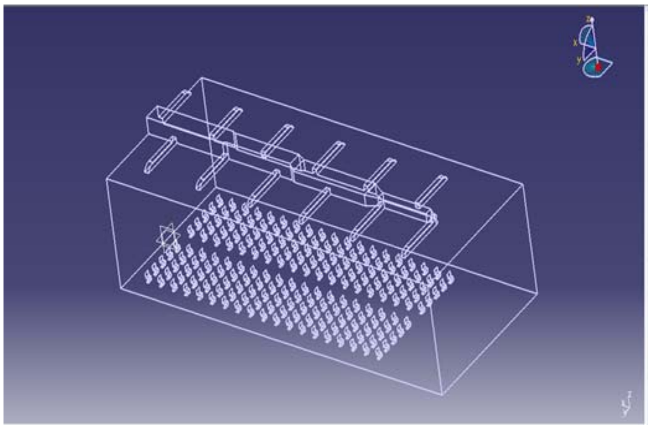


Fig 2: Existing (Diffuser) HVAC systems using CATIA

Proposed Hvac System

The Proposed designing of the Grid type of modeling are created using Autodesk Revit 2015 & CATIA software and also designed air conditioning system has to use the openings of this ventilation system for incoming and outgoing air. This proposed design of the grid base auditorium gives the more thermal comfort condition when compared to the diffuser base auditorium. So this type of condition or performance are analyzed. The proposed alterations to the air distribution system result in the addition of much more air handling units and exhaust fans. The supply to the front stalls is reconfigured to an under floor displacement system, with the supply air temperature of this portion of the system raised to 18°C. The stage cooling is via high-level jet diffusers grilles (above the boxes), replacing the wall grilles, with the supply component via the wings reduced. The sidewall return via grilles in the passengers and corner levels remains as per existing, with are balance in the stall areas. The under floor return is replaced by the displacement supply system mentioned earlier, with the ceiling supply diffusers above the front stalls altered to act as return. Additional ceiling return is added above the side corner to supplement exhaust from the auditorium. This can be seen in *Figure 3&4* below

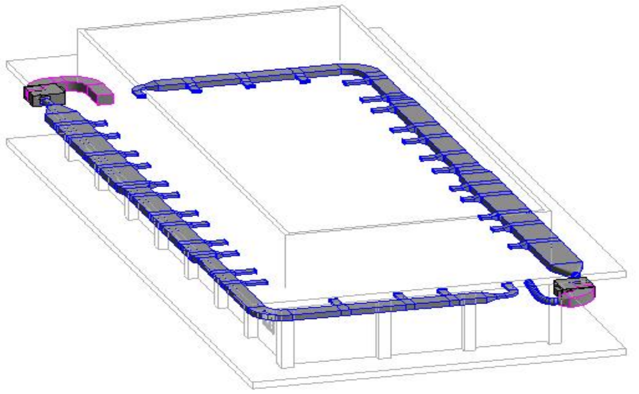


Fig 3: Proposed (Grid) HVAC using Revit 2015

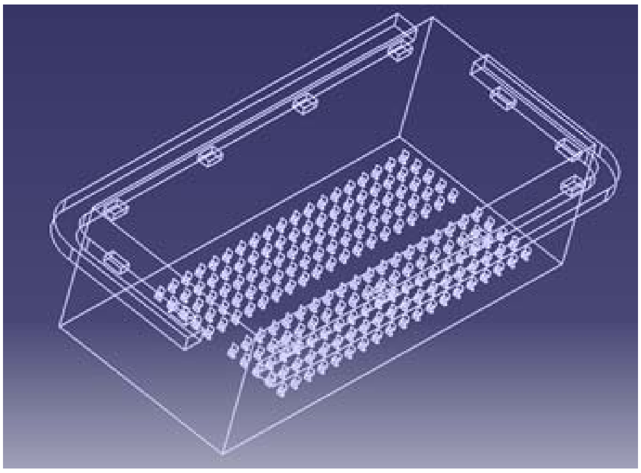


Fig 4: Proposed (Grid) HVAC system using CATIA

Simulation Parameters

Software

The CFD software package Phonics was used in this assessment. Phonics provides a full capability for grid generation, solution and post-processing via 3-D or text input. Phonics has been validated under a number of applications, including in building environmental simulation (Gaspar, PD et al. 2003). The Flair module of Phonics is dedicated to CFD airflow visualization and analysis applications within the built environment and provides the following capabilities; steady state and transient CFD analysis, turbulence models (including the k-remodel), buoyancy models, conjugate heat-transfers, a library of materials based on CIBSE reference data and a range of HVAC-related objects, including diffusers and fans. Computational fluid dynamics is a time intensive process. In order to reduce the model development and calculation time for this complex simulation, it's essential to make simplifications to allow convergence of the simulation within a finite time. Further, as Phonics makes use of a structured grid angled and curved geometry can result in increased convergence times if not properly considered. The following table contains a list of simplifications, and comments on the justification.

Grid Generation

The grid spacing implemented in the model was 167x140x92, or 2,150,960 cells. This resulted in ineffective resolution of approximately 0.25-0.3m.Note that the grid was able to expand where little detail was required (generally only in the z direction above the corner zone), such that resolution in matched the nominal unit size unoccupied areas. Generally, this is a coarse grid given the distribution of supply, exhaust and loads through the space. However, increases in resolution were not feasible due to the limitations of 32-bit computing; sensitivity analysis was undertaken of test spaces representing half model. This analysis was undertaken to determine the impact of the course grid. It involve creating a small model of a Diffuser with two separate grids, one a course grid and the other a fine grid. The difference between the two models was compared in this sensitivity analysis and no significant difference was observed.

Occupants

Occupants were modeled as blocks heat sources composed of domain material (in this case air) withal fixed heat flux, occupying a seat that provided obstruction to air flow. Individual members, with seat, occupied a space of 0.5m by 0.5m by 1.2mhigh. They were considered effectively "at rest", And thus assigned a 65W sensible load. On the stage equipment and performers were represented by a fixed 60W/m² heat load with20 W/m² heat load in the wings.

Obstructions

Obstructions, such as walls, ceilings and rows were considered to have sufficient thermal mass to be insensitive to local conditions in minor time scales, thus they were given a fixed surface temperature due to thermal history (pre-performance conditioning).

Ventilation System

Cooling mode operation under full occupancy was chosen for this analysis. Perfect commissioning is assumed when assigning flow rates to HVACelements, in that nominal flow values are achieved Note that in comparison to heating mode and isothermal cases, it has been found that turbulence models are generally poor predictors of ventilation flow in cooling mode (Feinberg, G et al 2005), with the standard k-ε turbulence model provides adequate performance (Cao, G 2007) and was thusadopted for this simulation.

Diffusers

Given the coarseness of the grid, a simple diffuser type was used based on a grille/nozzle model. The actual diffuser type was simulated by selecting face velocity, aspect and angle to appropriate values depending on whether the diffuser was a ceiling mounted register, linear slot, under floor or wall register. It is not expected that proper diffusion will be achieved throughout the model, but both models will be subject toothsome limitation and thus are comparable.

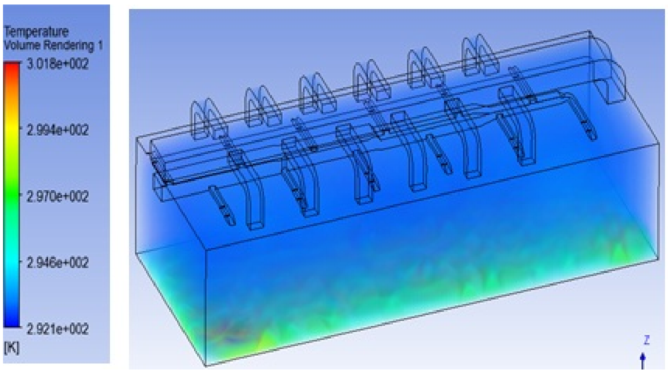
Return air

The return air outlets were represented in the model by square face fans, which function by extracting air from the model at points. The volume of air for a particular fan was determined by the chosen face velocity.

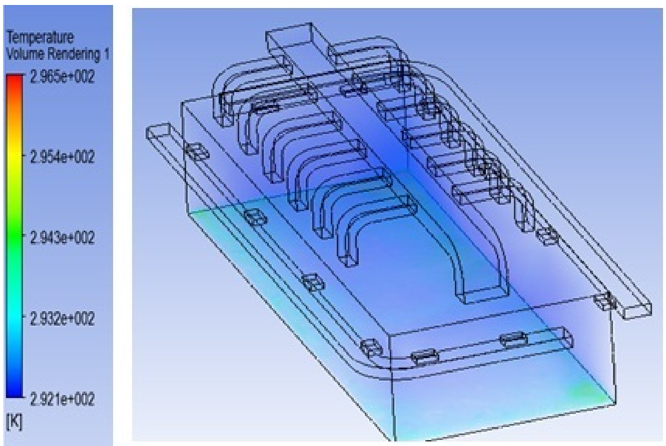
4. Results and Discussion

As discussed above two modeling scenarios were investigated. One being the existing system as currently designed and operating, the other being the system as proposed by the mechanical engineers. The purpose of the modeling was to determine if the proposed solution was going to solve some of the system problems and also to identify if there are additional areas that require further design review and consideration. Results of the two models are shown below for temperature and velocity in plan view at the stalls level (the area with most complaints) and in section view through the center of the auditorium.

Temperature Plot Elevations

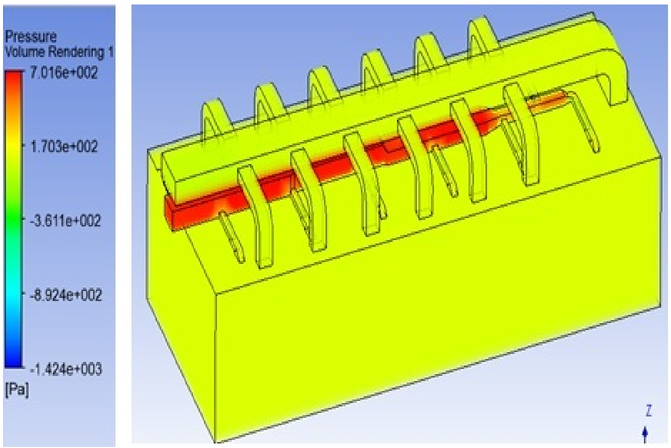


Elevation showing Existing Conditions

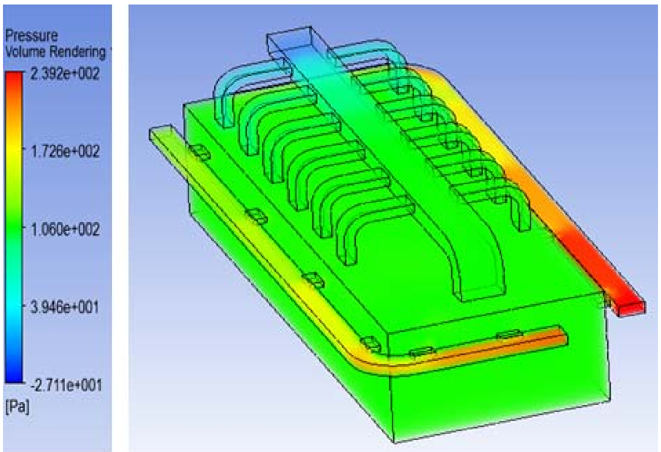


Elevation showing Proposed Conditions.

Pressure Plot Elevation View

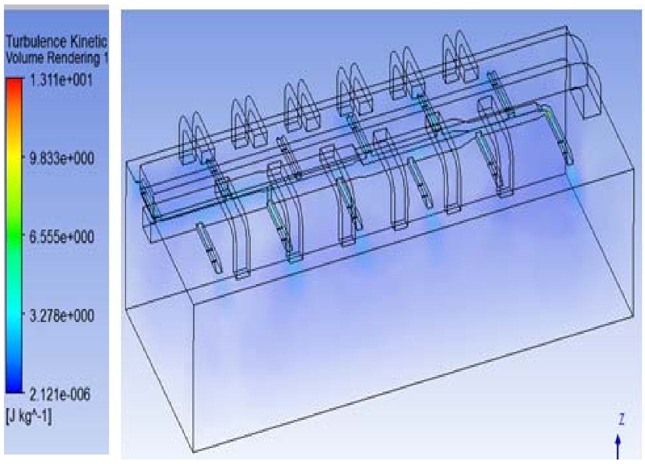


Elevation View showing Existing Conditions

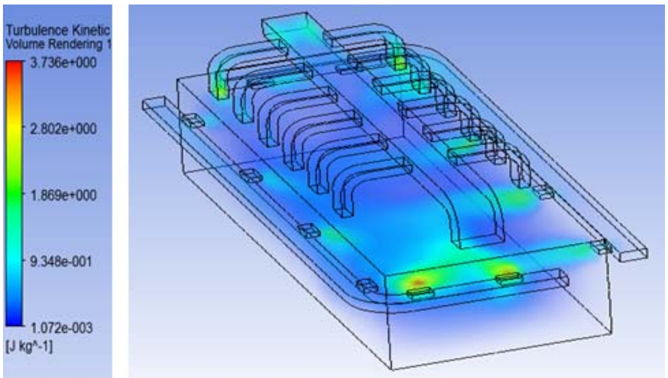


Elevation View showing Proposed Conditions.

Turbulence kinetic Energy Plot Elevation View

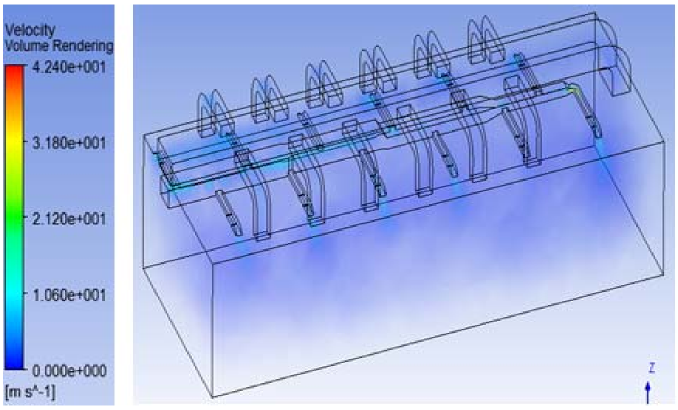


Elevation View showing Existing Condition

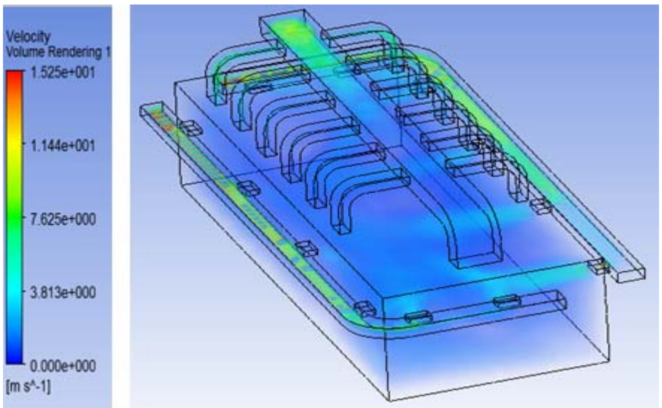


Elevation View showing Proposed Conditions.

Velocity Plot Elevation View



Elevation View showing Existing Conditions



Elevation View showing Proposed Conditions.

5. Conclusion

The results of the CFD analysis indicated that the proposed alterations generally achieve the following when compared to a model of the existing

- ❖ Delivery of supply air from diffusers to the overall auditorium and appears to improve.
- ❖ Local temperature variations may be more moderate.
- ❖ Gradually increases the amount of air flow velocity from the grid base auditorium model.
- ❖ Circulation patterns in the void space appear to be more moderate and hence air dumping may be less likely to occur.

It should be noted that in the CFD simulation, both the existing and proposed systems demonstrate stagnation of air and higher temperatures in the back stalls and circle area. Feedback from users of the auditorium would also support this finding of temperature in these areas.

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