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# *The Fluid Flow Simulation of the Thermal Comfort in Theatre*

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***Abstract.*** **This paper examines the use of Computational Fluid Dynamics (CFD) simulations to improve thermal comfort in enclosed spaces, such as theatres, halls, and offices. Thermal comfort is crucial for occupant well-being and productivity, and is influenced by various factors, including air temperature, humidity, and airflow. To create tailored models for specific spaces, we suggest using CFD simulations to predict airflow patterns and temperature distribution, thereby identifying discomfort zones. This research aims to optimize thermal comfort and improve building design and energy efficiency by iteratively adjusting ventilation strategies. The practical applications of this approach include improved design and construction, as well as retrofitting existing buildings. To achieve this, CFD simulations should be integrated into the design phase to proactively address thermal comfort issues and achieve energy-efficient layouts. Customising CFD models for existing buildings allows for the analysis of airflow patterns and optimisation of ventilation strategies to enhance thermal comfort. HVAC systems can be evaluated using CFD to identify areas for improvement and select energy-efficient solutions, leading to enhanced energy efficiency. The benefits of these improvements include enhanced well-being and productivity, as improved thermal comfort can lead to better occupant health and focus, ultimately boosting productivity. Additionally, the risks of Sick Building Syndrome (SBS) can be reduced. CFD analysis can help reduce the risks of Sick Building Syndrome by optimizing ventilation and improving indoor air quality. In the future, it is recommended to integrate CFD simulations with Building Information Modelling for comprehensive thermal comfort analysis. This study highlights the potential of CFD to optimize thermal comfort in enclosed spaces by promoting occupant well-being and energy efficiency through iterative ventilation adjustments. It is important to adhere to established standards when integrating CFD.**

***Keywords: CFD simulation, theatre, thermal comfort.***

## I. INTRODUCTION

Theatres are places where many people gather for the purpose of breaking away from everyday activities, spending pleasant time with loved ones and friends and enjoying a favorite performance or concert. A large part of theatres are closed spaces that need effective ventilation in order to create a comfortable thermal environment for visitors. Various studies have been done on the effect of the ventilation system on indoor comfort. These studies can help to apply the software product more effectively especially for places where the ambient temperature is quite high in summer months and quite low in winter [1], [2], [3]. In addition to all this, the improvement of the thermal conditions will also lead to an increase in the energy efficiency of the enclose spaces. Source [4] aims to identify an acceptable temperature range in residential buildings by investigating correlation of comfort temperature with indoor and outdoor temperatures using “Comfort threads” and elucidating the effect of adaptive measures on the energy saving potential of residential premises.

Various ways to improve thermal comfort using simulations are given in [5]. The same were compared with the results obtained from the present study and thus validated.

In general, in places where many people gather, regardless of the purpose, to ensure the thermal comfort of the occupants, standards for the main influencing factors are used. These are ASHRAE 55 [6] and ISO 7730 standards [7], based on which the main parameters Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) are calculated. These two parameters are set in the simulation to evaluate people's satisfaction with the thermal conditions in the theatre. Based on these, subsequently, the simulation settings can be changed to provide a better thermal environment.

Source [8] presents simulation results of thermal comfort and indoor air quality affected by partitions in an air-conditioned building. Reference [8] was used as the reference algorithm to perform the present work.

The simulation is carried out by setting parameters for convective heat transfer and radiation; setting boundary and other conditions; and analysis of the achieved thermal comfort through post-processing including the parameters PMV and PPD.

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## II. MATERIALS AND METHODS

### *A. CAD model*

Full-cloud CAE simulation software Sim Scale is used to perform the simulation for thermal comfort in a theatre [9]. Initially, the CAD model must be prepared to perform the simulation. In this case, is necessary to extract the flow volume, which can be done either by using the model imported into the software or by selecting the faces manually. For greater clarity about the specifics of flow extraction, a self-extraction with topological objects set is performed. This is also done for a specific problem, where the geometry of the walls and the type of extraction (Internal Flow Volume or External Flow Volume) must be set. In the present case, the Internal flow volume extraction mode is used.

The given set of topological objects in the creation of a CAD model are actually the boundary conditions that are set in cases where a solution to a boundary value problem has to be found as in the case of Internal heat flow, Fig. 1 [9]. The same applies if the heat flow is external.

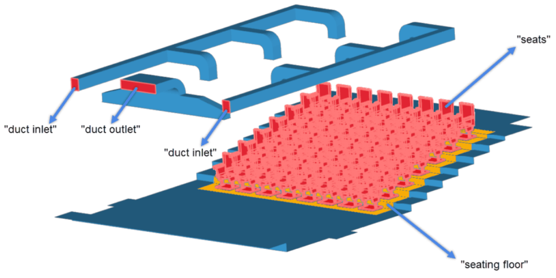

Fig. 1. Set of topological objects [9]

For each of the boundary conditions, the main parameters affecting it are adjusted. Such are:

- gravity in the γ direction;
- air as a material with its inherent properties;
- velocity inlet;
- pressure outlet on the air entrances and the exit;
- fixed seats temperature value;
- "No-slip" walls with fixed temperature value;
- topological entity set.

The Convective Heat Transfer analysis type is selected to create the simulation, which incorporated the "K-omega SST" turbulence model [10]. This model is extremely applicable and preferred in Computational Fluid Dynamics (CFD) over other RANS models, as it combines two other models, the Wilcox k-omega and the k-epsilon. It includes two transport equations for two dependent variables: k – turbulence kinetic energy and ω – specific dissipation rate.

Using the K-omega SST model provides a better separation of the fluid flow and accounts for its good behavior and the way the principal shear stress is transmitted through the boundary layers if adverse pressure gradients are present.

In [9], the initial values of turbulent kinetic energy k and specific dissipation rate ω are given, but the boundary conditions for these variables can be changed.

If necessary, radiation can be included in the Convective Heat Transfer analysis type via the Diffuse View Factors Model. View factors are used to calculate the amount of radiation exchanged between two surfaces and depend only on the geometric relationships between them. In the present case, radiation is not included in the simulation, since the air is set as a medium that is transparent and assumed to be undisturbed.

### *B. Result Control and Mesh Generation*

To solve specific software computations is used the Results Control Elements. These are thermal comfort parameters according to standards [6] and [7] and the inclusion of two additional scalars (PMV and PPD) that can be influenced by these parameters.

To perform the simulation calculations for each specific problem, an appropriate mesh is selected depending on the complexity of the geometry. In the present case, a standard meshing algorithm is used, suitable even for the most complex geometries. It gives good results and is quite automated. The mesh that is generated is a 3D unstructured mesh using tetrahedral or hexahedral elements, Fig. 2.

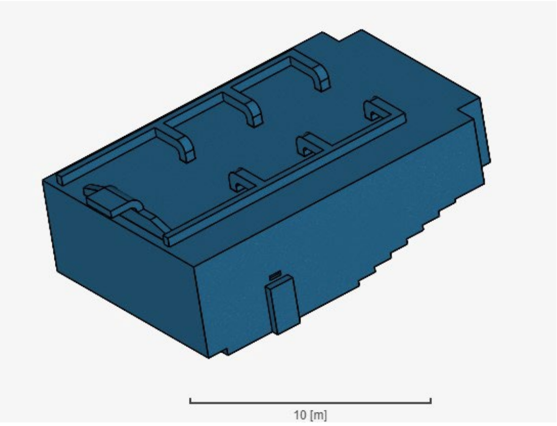

Fig. 2. View of mesh geometry

## III. RESULTS AND DISCUSSION

After starting the simulation and completing the calculation, an integrated post-processor is used to visualize the main parameters giving an estimate of the thermal comfort in the theater hall.

### *A. Predicted mean vote*

PMV in Fig. 3 shows the average value that the occupants would give for thermal sensation according to the set parameters in the simulation. If the heat balance between the heat emitted by the body and that received by it is zero, then an ideal thermal environment and satisfaction has been achieved, i.e. the PMV value should be zero.

Limit values for PMV according to ASHRAE Standard 55 are between -0.5 and 0.5 [6]. More extended ranges are given in [7].

- Hard limit: [-2 ÷ +2];
- New buildings: [-0.5 ÷ +0.5];
- Existing buildings: [-0.7 ÷ +0.7].

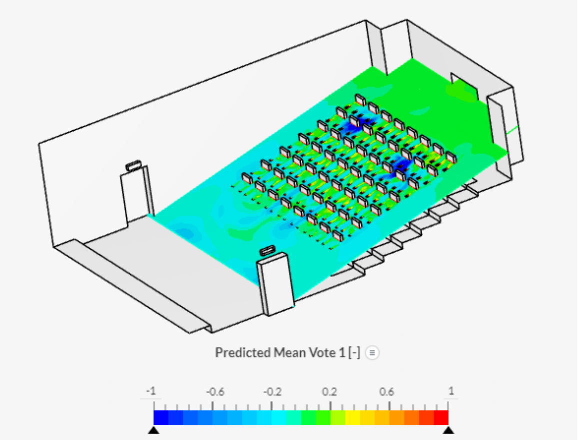

Fig. 3. Predicted mean vote

In Fig. 3 the colour scale of the PMV value change in the range from -1 to 1 (from dark blue, blue, light blue, green, yellow, orange to red, respectively) is shown. It can be seen that the PMV is not up to standards for the entire area and heat balance is not achieved, although in most of the area the PMV value is within the permissible limits and only in some small regions the PMV value is less than - 0.5, and in others exceeding 0.5.

### *B. Predicted percentage of dissatisfied*

In Fig. 4 PPD represents the percentage of people expected to experience some local discomfort. It can be caused by:

- large temperature differences in height ;
- air flow in the presence of natural ventilation;
- unwanted cooling or overheating of the body in the presence of forced ventilation or in the absence of such at very low and very high outside temperatures.

According to [6], if the obtained degree of satisfaction is above 80%, good thermal comfort has been achieved in the closed room. The remaining 20% of dissatisfaction may be related to individual discomfort related to all or some of the factors affecting PMV. PPD can vary from 5% to 100%, depending on where the occupants are located and based on the calculated PMV. For comfort standards to be met, the PPD must be lower than 20% for every point in the space.

A colour scale with a range of 5% to 50% is also used for PPD analysis, which corresponds to colours from dark blue, blue, light blue, green, yellow, orange to red. Considering the results obtained for the PMV value, again there is no complete satisfaction, since in the same zones the PPD value is higher than the permissible limit value of 20%.

As a conclusion from the Fig. 3 and Fig. 4, it can be said that readings can be a basis for improving the thermal environment of the theatre and approaching the ideal, thereby increasing the satisfaction of the occupants. This can be achieved practically, for example, by improving the ventilation systems of the rooms and changing the values of the thermal parameters set in the simulation.

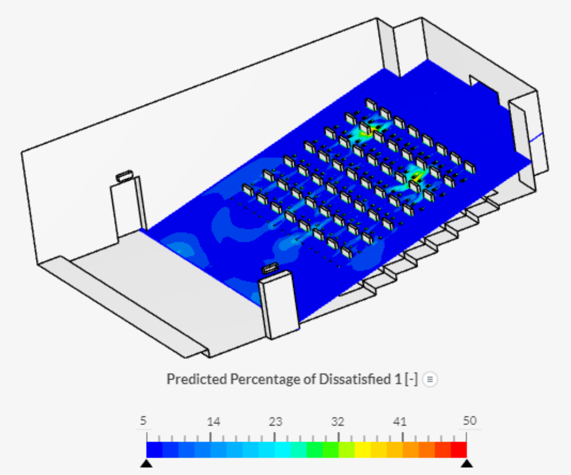

Fig. 4. Predicted percentage of dissatisfied

## IV. CONCLUSION

In conclusion, this paper presents a significant advancement in enhancing thermal comfort in confined spaces through numerical approaches. Separate simulation models were employed for flow volume extraction with topological objects set and for Convective Heat Transfer and Radiation, allowing for effective assessment and analysis of the key parameters influencing thermal comfort in theatres.

The use of Computational Fluid Dynamics (CFD) simulation with the K-omega SST turbulence model allows for a thorough analysis of fluid flow, considering factors such as adverse pressure gradients. The integration of post-processing and mesh analysis also improves the evaluation of thermal comfort.

The simulation results, expressed through the PMV and PPD parameters, are based on established thermal comfort standards ISO 7730 and ASHRAE 55. These parameters provide a visual representation of the thermal conditions across the researched area. Precise analysis of these parameters can help propose improvements in ventilation systems and simulation parameters, thereby enhancing occupant satisfaction and energy efficiency in enclosed spaces.

The theoretical contributions of this study are based on the advanced modelling techniques used and the thorough analysis of results. The findings provide valuable insights for optimizing indoor environmental quality, aligning with established standards, and informing decision-making processes in building design and operation.

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