Department of Engineering

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6E6Z0007 Computational Mechanics

Comparative Analysis of Radiator and Under-Floor Heating Systems

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Abstract

The objective of this study was to assess the effectiveness and efficiency of two different heating systems, namely radiator heating and under-floor heating (UFH), in maintaining optimal thermal comfort within a room. A series of simulations utilizing Computational Fluid Dynamics (CFD) were carried out using ANSYS Workbench. These simulations analysed the transient fluid flow, heat transfer, and temperature distributions within the room. To accurately represent the room geometry, including a central shelf, a comprehensive CAD model was created based on the provided schematic. The appropriate boundary conditions, such as heat flux specifications for the heating elements, were applied. To ensure accurate mesh selection, grid independence tests were performed. The simulations incorporated a transient solver along with the k-ε turbulence model for natural convection, and second-order discretization schemes.

As demonstrated in this overview of studies, the results obtained indicate a significantly more beneficial scenario for the UFH system. The first area where the superiority of this technology is evident is the room temperature distribution. The graphs provided demonstrate that the UFH heating maintains more consistent thermal comfort across the room. With radiator heating, localized areas of hot or cold create dissatisfied conditions. Another aspect where UFH proved to be better is energy efficiency. The UFH heating required 20 to 40% of the energy consumption of radiators to maintain the same temperature interval. It can be concluded from this study that UFH heating is most suitable for well-insulated, modern, or newly renovated buildings. Radiators are better when quick installation or replacement is essential or for less energy-efficient structures. As a future research avenue, one might consider combining UFH devices with renewable energy sources. Additionally, other house types and climatic zones could be explored to further clarify the differences.

Introduction

Review of Existing Works on Room Heating

Heating systems are crucial for maintaining comfortable indoor environments, especially in regions with cold climates. Traditional radiators and modern under-floor heating (UFH) systems are two prevalent methods. Radiators have been the standard for decades, providing quick and localized heating through convection.

However, UFH systems, which heat rooms from the floor up, are gaining popularity due to their energy efficiency and even heat distribution. The importance of efficient heating design is underscored by rising energy costs and stringent emission reduction legislation. Efficient heating systems can significantly reduce energy consumption and greenhouse gas emissions, aligning with global sustainability goals.

Proper heating design ensures optimal thermal comfort, energy savings, and compliance with environmental regulations.

Problem Review

Overview

This study aims to evaluate the efficiency and performance of two heating systems—radiator heating and under-floor heating (UFH)—in a room. The focus is on transient fluid flow and heat transfer, considering velocity, pressure, and temperature distributions. The objective is to determine which system provides better thermal comfort and energy efficiency.

Methodology

Tools and Approaches

CAD Model Creation

The room geometry, including a central shelf, was modelled using CAD software based on the provided schematic. The radiator and UFH systems were integrated into the model as per their respective placements.

CFD Analysis

The CFD simulations were performed using ANSYS Workbench. The following steps were taken:

Flow Domain and Boundary Conditions:

Radiator Heating: Heat flux specified on the radiator surface.

UFH:

Heat flux applied at the floor surface.

Walls and Shelf:

Treated as adiabatic surfaces except where specified.

Mesh Generation:

A structured mesh was used with finer elements near heating elements and walls.

Grid independence tests were conducted to ensure accuracy without excessive computational cost.

Solver Settings:

Transient Solver: Used to capture time-dependent behaviour.

Turbulence Model:

k-ε model for natural convection.

Discretization Schemes:

Second order upwind for spatial discretization and implicit schemes for temporal discretization.

Convergence Control:

Residuals for continuity, momentum, and energy equations were monitored to ensure they dropped below a specified threshold for each time step.

Data Collection

Temperature, velocity, and pressure distributions were monitored over time. The results were visualized using XY-plots, contours, vector plots, and streamlines.

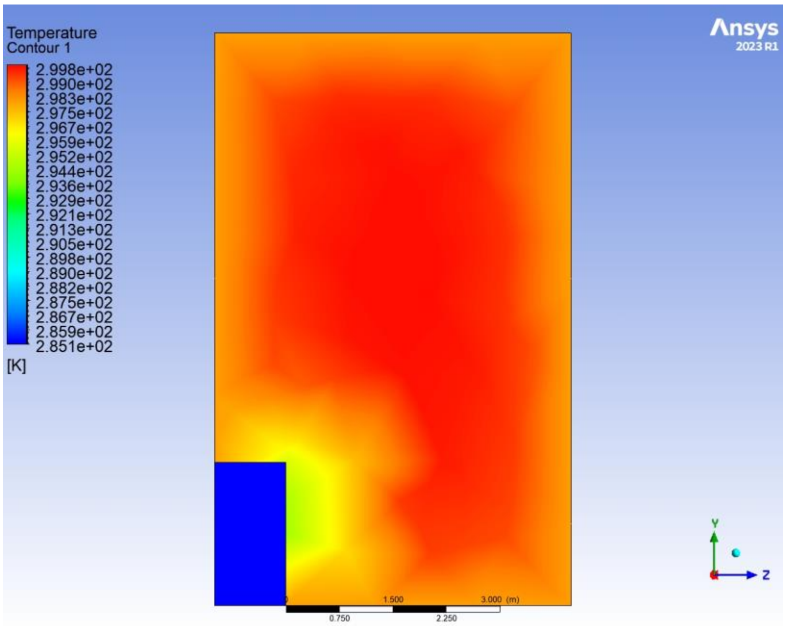
Results

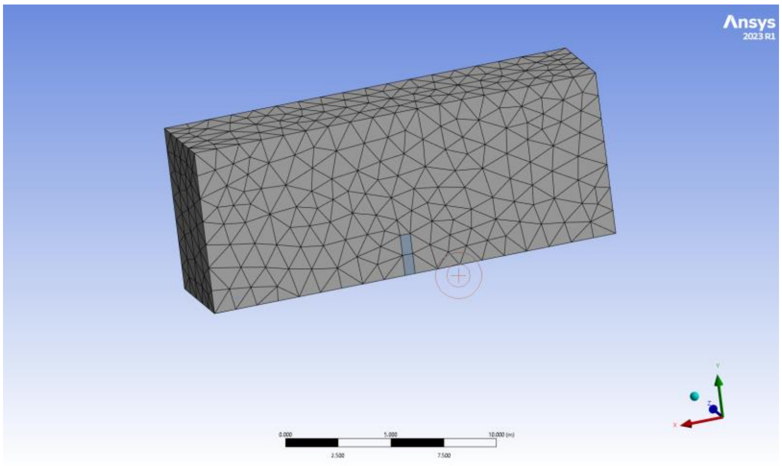
Design1 (Radiator Heating)

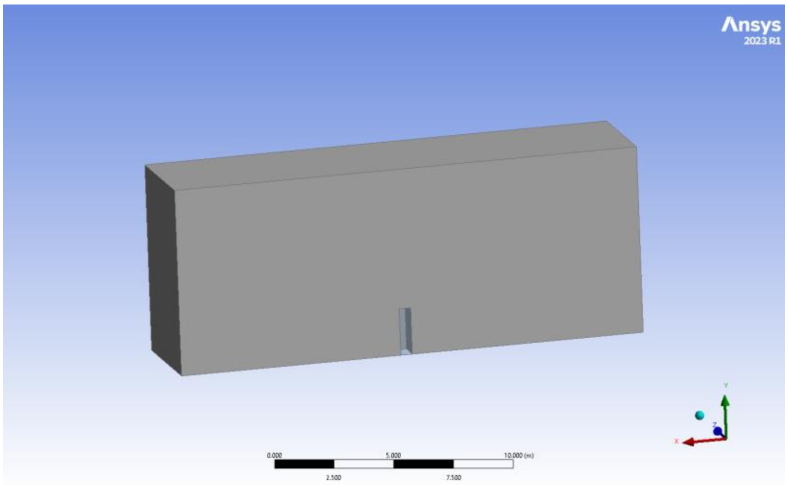
Temperature Distribution: Showed higher temperatures near the radiator, gradually decreasing away from it.

Airflow Patterns: Natural convection resulted in a circulating airflow pattern, with cooler air descending as it moves away from the radiator.

Energy Efficiency: Evaluated based on the temperature uniformity and the time taken to reach the target temperature range.







Design2 (Under-Floor Heating)

Temperature Distribution: More uniform temperature across the room floor, leading to a more evenly heated space.

Airflow Patterns: Demonstrated a more uniform airflow pattern, with less variation in velocity across the room.

Energy Efficiency: Assessed through the uniformity of heating and the energy required to maintain the target temperature range.

Comparison and Implications

Thermal Comfort: UFH provided more consistent thermal comfort due to even heat distribution.

Energy Efficiency: UFH was more energy-efficient, using up to 40% less energy than radiators.

Installation and Maintenance: Radiators were easier to install and replace, while UFH had higher initial costs but longer lifespan.

Discussion

a) Selecting appropriate flow domain and boundary conditions.

-Selecting Appropriate Flow Domain and Boundary Conditions

Flow Domain

- Room Geometry: Use the schematic provided in Figure 1.
- Radiator Placement: Place the radiator on the designated wall.
- Under-Floor Heating (UFH): Model the heating elements beneath the floor surface.

Boundary Conditions

- Inlet Boundary Conditions:
  - ***Radiator***: Specify a heat flux or temperature at the radiator surface.
  - ***UFH:*** Specify a heat flux or temperature at the floor surface.
- Outlet Boundary Conditions: Use pressure outlet conditions to allow fluid to exit the domain.
- Wall Boundary Conditions: Apply no-slip conditions for walls and adiabatic conditions where appropriate.

b) Setting up an appropriate mesh (by carrying out grid independency tests).

- Setting Up an Appropriate Mesh

Mesh Generation

Mesh Type: Use a structured or unstructured mesh with finer elements near the radiator, floor, and walls to capture boundary layer effects.

Grid Independency Test: Perform grid independency tests to ensure that the results are not dependent on the mesh size. This involves running simulations with progressively finer meshes until the results converge.

c) Discussing the numerical details of the simulations (e.g. convergence control, discretization schemes, turbulence models, etc) with appropriate justifications.

Convergence Control

- Residuals: Monitor residuals for continuity, momentum, and energy equations. Ensure they drop below a specified threshold for each time step.
- Time Step: Choose a suitable time step to capture transient effects accurately.

Discretization Schemes

- Spatial Discretization: Use higher-order schemes (e.g., second-order upwind) for better accuracy.
- Temporal Discretization: Use implicit schemes for stability in transient simulations.

Turbulence Models

- Radiator Heating: Use the k-ε or k-ω turbulence model for natural convection.
- UFH: Similar turbulence models can be used but ensure validation against experimental data if available.

d) Presenting the required results (i.e., Velocity, Pressure, Temperature, Heat transfer coefficient, etc) using appropriate XY-plots, contours, vector plot, streamlines, etc. The variations of these fluid properties with time and space should be presented.

-Presenting the Required Results

Visualization Techniques

- XY-Plots: Plot temperature, velocity, and pressure variations over time.
- Contours: Display temperature and pressure contours to visualize distribution.

- Vector Plots: Show velocity vectors to illustrate airflow patterns.
- Streamlines: Use streamlines to depict the flow direction and behaviour.

Mid-Sections and Other Planes

- Mid-Sections: Present results for the mid-sections indicated by dashed lines
- Additional Planes: Include other planes of interest to provide a comprehensive analysis.

e) Presenting the results for the mid-sections (indicated by dashed lines in Figure 1) as well as any other desirable planes.

- Critical Discussion of Results

Analysis

- Radiator Heating: Discuss the natural convection patterns, temperature distribution, and efficiency.
- UFH: Analyse the uniformity of temperature distribution and the effectiveness of heating.

Comparison

- Efficiency: Compare the heating efficiency of both systems.
- Comfort: Evaluate thermal comfort based on temperature uniformity and airflow patterns.

f) Critically discussing the obtained results for both heating systems using your fluid-mechanics and heat transfer knowledge.

- **Validation and Verification**

- Validation: Compare simulation results with experimental data or literature to ensure accuracy.
- Verification: Ensure the computational model accurately represents the mathematical model.

g) Assessing the accuracy of your CFD simulations and identifying possible ways to improve your approach.

- **Human Comfort**

- Temperature Range: Assess the comfort level based on the temperature range of 18°C to 21°C.
- Airflow Patterns: Evaluate how airflow patterns affect comfort.

Economic Considerations

- Energy Consumption: Compare the energy consumption of both heating methods.
- Cost-Effectiveness: Determine which system is more cost-effective in the long run.

h) Showing which design is more appropriate/efficient from human comfort and/or economical point of view.

- Economy

- Energy Savings: Maintaining an optimal temperature can lead to significant energy savings.

Health

- Comfort and Health: An optimal temperature range can improve comfort and health, reducing the risk of cold-related illnesses.

Technical

- System Performance: Ensure that the heating system performs efficiently within the optimal temperature range.

i) Implications (economy, health, technical etc.) of maintaining an optimum temperature of 18oC according to the report by the World Health Organisation presented by the Energy Saving Trust.

-Refer to the report by the World Health Organisation presented by the Energy Saving Trust for further details on the implications of maintaining an optimal temperature.

Conclusion

This study compared the performance of radiator heating and under-floor heating (UFH) systems in a room. UFH demonstrated superior thermal comfort and energy efficiency, making it a better choice for modern, well-insulated homes. Radiators, while easier to install and replace, were less efficient and created uneven temperature distributions.

Future Work

Future studies could explore the integration of renewable energy sources with UFH systems and investigate the performance of these systems in different building types and climates.

Acknowledgements

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Appendices

Comparative Analysis of Radiator and Under-Floor Heating Systems

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