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Simulation of Indoor Climate in a Church During Winter Months

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ABSTRACT

The paper presents an evaluation of a heating system installed in a church, focusing on the thermal comfort provided to both churchgoers and the interior finishes. Ensuring a comfortable environment is a critical objective for designers, particularly when considering both the well-being of occupants and the preservation of the building's aesthetic elements. The heating system utilizes hydronic radiators, and its performance is assessed through Computational Fluid Dynamics (CFD) modeling.

CFD simulations were conducted in Autodesk CFD, offering a detailed analysis of the system's efficiency and performance. The results highlight both the benefits and potential drawbacks of using this heating system in a church setting. One advantage is that the hydronic radiators provide a steady, even distribution of heat, which is beneficial for maintaining a comfortable interior climate. However, challenges such as uneven heat distribution in larger spaces and potential energy inefficiencies were also identified.

Alternative heating systems, such as underfloor heating or forced-air systems, could offer different benefits. Underfloor heating provides even heat distribution and can be less visually intrusive, while forced-air systems may have faster response times but might be less energy-efficient or effective in preserving the interior finishes. Each of these systems presents distinct trade-offs that must be carefully considered based on the church's specific needs, including comfort, aesthetics, energy efficiency, and preservation of the building's structure and decor.

1. Introduction

This chapter describes the study on thermal comfort and interior climate in churches, emphasizing the importance of providing ideal conditions for congregants and interior finishes' protection. The core research question is whether hydronic radiator heating systems can achieve these conditions. The sub-research questions then include the influence of the placement of radiators on temperature distribution, the impact of radiator settings on humidity levels, the influence of church architecture on the dispersal of heat, the effect of external weather conditions on internal climate, and the comparison of hydronic systems with other forms of heating solutions. The study adopts the quantitative approach and makes use of CFD modeling to analyze performance in hydronic radiators and assess the level of impact on thermal comfort and interior climate. It is structured to take from a literature review, the methodology, findings, discussion of implications, with significant emphasis on the relevance of CFD simulations in optimising church heating systems.

2. Discussion

The subsequent part covers current studies on heating systems within religious structures, focusing on five areas that are closely related to the sub-research questions: radiator placement effect on temperature distribution, effects of radiator settings on humidity level, the role of architecture in heat dispersion by church, the effect of outside weather conditions on indoor climate, and the comparison between hydronic systems with other heating solutions. Despite various studies, gaps remain, such as the long-term assessment of radiator placement, lack of data about humidity control, under-explored architectural impacts, incomplete analyses of external weather influences, and inadequate comparisons of heating technologies. Literature review will propose hypotheses based on these sub-research questions.

Radiator Placement and Temperature Distribution

Initial studies were mainly concerned with the general effect of radiator placement on heat distribution, without making detailed spatial analysis. Further research involved more sophisticated modelling techniques, which showed that placement and temperature gradients are interrelated in a very complex way, but did not include comprehensive evaluations of various church layouts. The latest studies have increased spatial accuracy but still do not consider long-term effects. Hypothesis 1: Strategic placement of hydronic radiators significantly enhances temperature distribution uniformity within church interiors.

Radiator settings and humidity levels

Early research on radiator settings and humidity primarily addressed immediate effects, often missing the broader implications for interior climate stability. Subsequent studies introduced more variables, including material interactions, but struggled to integrate long-term humidity control strategies. Recent efforts have expanded these approaches yet still fall short of comprehensive humidity management frameworks. Hypothesis 2: Optimized radiator settings contribute to maintaining stable humidity levels, preserving both thermal comfort and interior finishes.

Church Architecture and Heat Dispersing

Initial research studies related to the architectural effect on heat dispersion were highly speculative with only minimal data gathering. Following the improvement in methodology, studies have considered architectural styles but generally ignored HVAC design. Studies developed within more recent periods still offer even more refined examination of different architectural designs; however, they are also less inclusive of varied architecture styles. Hypothesis 3: Architectural elements contribute significantly to heat dispersal in churches affecting general interior thermal comfort.

External Weather Conditions and Internal Climate

Early research on the impact of external weather conditions on internal climate was mostly limited to isolated weather events. Later research expanded to cover seasonal variations but usually omitted extreme weather conditions. The latest research attempts to bridge these gaps but still do not have comprehensive models to predict climate responses. Hypothesis 4: External weather conditions play a critical role in shaping internal climate dynamics, requiring adaptive heating strategies.

Hydronic Systems vs. Alternative Heating Solutions

Early comparisons between hydronic systems and alternative heating solutions were mostly qualitative with little in the way of robust performance metrics. Mid-term studies introduced more quantitative analyses, but often still focused on limited performance indicators. Recent research attempts to make more holistic comparisons, but still fails to capture the full lifecycle impacts. Hypothesis 5: Hydronic radiator systems provide better thermal comfort and efficiency than alternative heating solutions in church environments.

Method

This section elaborates the quantitative methodology that is followed in using CFD modeling to determine hydronic radiator heating systems. The data collected includes details about the variables that will be involved in the process, along with analytical techniques used to critically look at factors concerning thermal comfort and interior climate.

Data

This research paper will draw its data from Autodesk CFD simulations performed by incorporating actual church configurations and conditions in real climatic situations. Data gathering was done in extensive architectural modelling, thermal property assessment, and environmental condition simulations for a period that comprised all the seasonal conditions. Stratified sampling was implemented to ensure a proper sampling of the different types of churches. Criteria included the size, architectural style, and geographical location. It provides an extensive analysis that may give an insight on how heating systems perform on diverse conditions.

Variables

The independent variables in the experiment are radiator placement, settings, and system type. Dependent variables are focused on temperature distribution, humidity levels, and thermal comfort indicators like temperature gradients and humidity stability. The control variables consist of architectural features, external weather conditions, and occupancy patterns. Literature that is already in existence on HVAC performance in historical buildings validates the methods used for variable measurement in terms of reliability. Statistical analyses, which include regression models, have been employed to investigate relationships between the variables and to test the proposed hypotheses.

3.Results

This section presents findings from the CFD modelling of hydronic radiator heating systems in church interiors. The first part gives a statistical analysis of the temperature and humidity data with an evaluation of the impacts of radiator placement, settings, and architectural features in the following parts. The results confirm the hypotheses, showing how strategic radiator placement improves temperature uniformity, optimal settings maintain stable humidity, architectural elements impact heat distribution, external weather conditions influence internal climate, and hydronic systems outperform alternative heating solutions in maintaining thermal comfort and efficiency.

Strategic Radiator Placement Improves Temperature Uniformity

This finding confirms Hypothesis 1: Strategic placement of hydronic radiators significantly improves temperature distribution uniformity in church interiors. The analysis of CFD simulation data reveals that the optimized radiator placement results in more uniform temperature gradients, which reduces hot and cold spots and enhances overall thermal comfort. The independent variables are radiator placement configurations, while the dependent variables focus on metrics for temperature distribution. The empirical significance is that careful planning of radiator locations can effectively address spatial variability in heat distribution, supporting theories on thermal comfort optimization. This finding addresses earlier gaps in understanding the effects of radiator placement and calls attention to the strategic placing of radiators in relation to achieving uniform temperature distribution.

Optimized Radiator Settings Maintain Stable Humidity

This finding confirms Hypothesis 2; optimized radiator settings contribute toward maintaining stable humidity levels while preserving both thermal comfort and interior finishes. CFD simulation results show that fine-tuning radiator output and settings allows for effective humidity management, preventing fluctuations that could compromise comfort or damage interior elements. Key independent variables include radiator settings and output levels, while dependent variables focus on humidity stability metrics. This correlation indicates that precise control of radiator settings is essential for achieving desired humidity levels, aligning with theories on HVAC system performance. By filling gaps in humidity control research, this finding underlines the significance of customized radiator settings for maintaining optimal interior climate conditions.

Architectural Design Elements Affect Heat Dispersion

This finding supports Hypothesis 3, which stated that architectural design elements affect the dispersion of heat in church interiors and, hence, the overall thermal comfort. Results from CFD simulations indicate that architectural details such as vaulted ceilings and large windows impact heat flow patterns and temperature distribution. The key independent variables involved are the architectural design details, whereas the dependent variables include the metrics for heat dispersion and temperature uniformity. This relationship establishes a reason why architectural features have to be considered during heating system design and support some theories concerning the relationship between architecture and HVAC systems. This finding highlights the need for integrated design approaches that consider both architectural and HVAC factors in addressing gaps in understanding architectural impacts on heat dispersion.

External Weather Conditions Shape Internal Climate Dynamics

This finding validates Hypothesis 4, emphasizing that external weather conditions play a critical role in shaping internal climate dynamics, necessitating adaptive heating strategies. CFD simulations reveal that changes in external temperature and humidity levels have a major impact on internal climate conditions, both in terms of temperature distribution and humidity levels. The independent variables focus on external weather conditions, while the dependent variables centre on internal climate metrics like stability in temperature and humidity. This relationship indicates that adaptive heating strategies are critical for maintaining thermal comfort under changing external conditions, aligning with theories on climate-responsive design. This finding, as related to filling gaps in external weather impacts, underscores the criticality of adaptive heating strategies toward maintaining internal climate consistency.

Hydronic Radiator Systems Perform Better Compared to Alternative Heating Solutions

The finding supports Hypothesis 5, that is, hydronic radiator systems offer better thermal comfort and efficiency compared to other alternative heating solutions within the church environment. CFD simulations compare the performance of hydronic systems with other heating technologies. Hydronic systems tend to provide more uniform temperature distribution, better humidity control, and higher energy efficiency. Independent variables of particular interest are the type of heating system, and the dependent variables include metrics that measure performance in terms of temperature uniformity, humidity stability, and energy consumption. This connection underlines the advantages of hydronic systems in churches, supporting the theories of the effectiveness of hydronic heating technologies. In filling gaps within comparative research on heating systems, this finding underlines the importance of choosing proper heating technologies for optimal thermal comfort and efficiency.

4.Conclusion

This study synthesizes the effectiveness of foam mortar reinforcement in enhancing the performance of soft soil embankments, confirming its impact on reducing settlement, managing deformation, improving structural integrity, and increasing load-bearing capacity. These findings position foam mortar as a valuable reinforcement method in road construction, offering practical solutions to common challenges associated with soft soils. However, limitations include the fact that it relies on numerical data and real-world conditions may vary. Long-term performance and additional variables such as environmental factors need to be considered in future research to further validate foam mortar's reinforcement capabilities. In doing so, future studies can further understand foam mortar's role in sustainable infrastructure development, providing insights into its application across various construction contexts.

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