DEVELOPMENT OF A BIM TOOL FOR AUTOMATIC LAOUT OF CASSETTE - TYPE INDOOR UNIT AND TEMPERATURE DISTRIBUTION SIMULATION IN AIR-CONDITIONED SPACES

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(Received: May 15, 2025; Revised: March 03, 2025; Accepted: March 15, 2025)

DOI: 10.31130/ud-jst.2025.23(9C).529E

Abstract - This study focuses on developing BIM Tools to support the design of HVAC (Heating, Ventilation, and Air Conditioning) systems and simulate temperature distribution in rooms based on the BIM model. The research team successfully developed a BIM tool on the Revit platform using the C# programming language and the Revit API, automating the placement of Cassette-type indoor unit according to two criteria: cost optimization and thermal comfort assurance. In addition, the study applied CFD (Computational Fluid Dynamics) simulation to assess temperature distribution and air velocity in the room. Simulation results show that thermal comfort indicators such as PMV, PPD, DR, and VATD all meet the standards TCVN 7438:2004 and ASHRAE 55-2020, confirming the effectiveness of this design. These results not only demonstrate the feasibility of integrating BIM and CFD in HVAC design but also open new development directions for the construction industry in Vietnam.

Key words - BIM tool; HVAC design; CFD simulation; thermal comfort; Revit API.

1. Introduction

In recent years, Building Information Modeling (BIM) has become an essential trend in the construction industry due to its ability to integrate, synchronize, and visualize the entire project lifecycle. BIM not only supports 3D design but also connects information across disciplines, enhancing coordination efficiency and minimizing errors during construction and operation. Among BIM applications, the HVAC (Heating, Ventilation, and Air Conditioning) systems field has received significant attention. This application was developed by scientists to support the design and construction of HVAC systems by improving energy efficiency, evaluating thermal comfort, and maintaining indoor air quality.

Currently, BIM has been utilized to support certain stages of HVAC system design. However, the placement of HVAC equipment, such as cassette air conditioners in the BIM environment, still involves many manual tasks, lacking specialized tools for automation and technical analysis integration. Researchers have addressed this issue by developing BIM applications in the HVAC field. Specifically, Liang et al. proposed a rule-based method for automated ductwork design that standardizes the layout workflow and reduces errors during system arrangement [1]. Wang et al. developed a BIM-enabled tool for automated HVAC design in office buildings and validated its effectiveness through experimental studies [2]. Notably, Qi et al. introduced an approach for automatically generating air-distribution layouts in office spaces, thereby improving design efficiency and mitigating spatial conflicts [3]. In addition, Liu and Huang integrated BIM with computational fluid dynamics to optimize HVAC design for pharmaceutical facilities, enhancing indoor environmental quality and increasing the accuracy of technical analyses [4].

Although previous studies have made positive strides in developing automated HVAC design tools in the BIM environment, some limitations persist when applied to practical projects. Most of these studies remain at the academic level, focusing on model or experimental plugin development without creating fully functional software for widespread use in real-world design projects. Additionally, these tools often focus solely on equipment placement without thoroughly evaluating post-design performance, particularly the integration of CFD simulation to assess thermal comfort within spaces.

Therefore, this study aims to develop a BIM tool capable of automatically selecting and placing Cassette-type indoor units in the Revit environment through the Revit API using the C# programming language. To evaluate the effectiveness of the generated designs, CFD simulation through ANSYS Fluent software was used to analyze temperature and air velocity distribution in air-conditioned rooms. The main objective of this simulation is to ensure that the designs not only meet technical requirements but also create an optimal comfort environment for users. The simulation results will be compared with the criteria specified in the Vietnamese Standard TCVN 7438:2004 (ISO 7730:1994) [5] the international standard ANSI/ASHRAE Standard 55-2020 [6] to evaluate the specific level of thermal comfort through factors such as uniform temperature distribution, airflow speed in the working area, thereby ensuring the system design meets all indoor environmental quality standards, avoiding discomfort due to unsuitable temperature or airflow factors.

2. Algorithm and mathematical models

2.1. Development of BIM tools using C# programming language

The algorithm for arranging cassette air conditioners in the BIM model was developed and implemented using the C# programming language within the Visual Studio environment, utilizing the Revit API library. The programming process consists of four main steps, as shown in Figure 1.

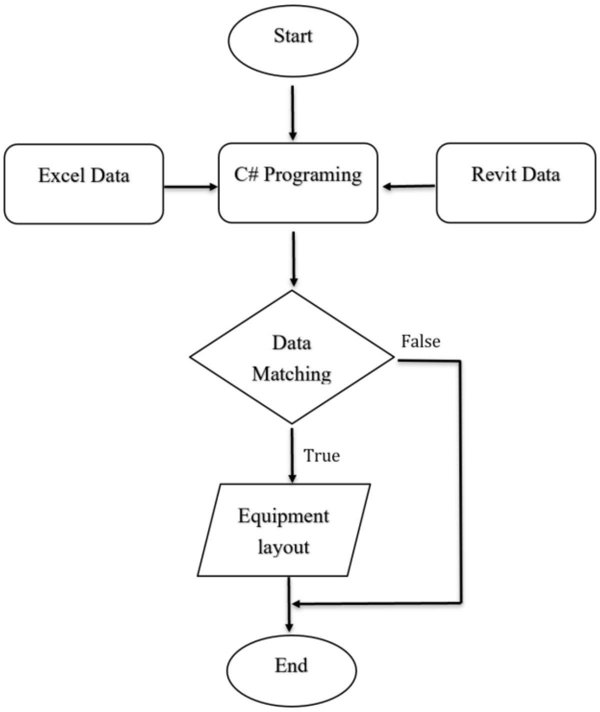

Figure 1. *Algorithm diagram*

- Step 1: Data Collection from the BIM Model

Before programming, it is essential to check the existing information within the BIM model to ensure that the program can accurately access and process the data. The data verification is carried out using the Revit Lookup tool, a plugin that allows direct access to the properties of each object in the model. The key information to be collected includes:

+ Room Name: Each room in the BIM model has a unique identifier, facilitating accurate data reference for each space.

+ Room Area and Shape: Used for calculating cooling loads and identifying suitable installation areas.

+ Wall Distance: Helps to restrict the placement area, ensuring compliance with the technical standards of the equipment.

+ Related Parameters: Ceiling height, wall types, and structural parameters affecting the arrangement of the cooling units.

- Step 2: Prepare Input Data from Excel

An Excel spreadsheet is prepared as the primary data source for the algorithm. This table includes two groups:

+ Room List: Contains room names and required cooling capacity (BTU/h or kW).

+ Cassette Unit Catalog: Lists the model names and corresponding capacities of each device.

Data Requirements:

+ Room names and model names in Excel must be consistent with the BIM model data to ensure accurate referencing.

+ The data must be complete, consistent, and in the correct format to avoid errors during automatic processing.

- Step 3: Algorithm Development using C# and Revit API

In the Visual Studio environment, the algorithm is programmed to perform the following key functions:

+ Data Retrieval: Access data from Revit and Excel, including room names, areas, shapes, cooling capacities, and the device list.

+ Data Analysis and Layout Proposal: The algorithm proposes a layout based on two criteria:

(i). Cost Optimization: Uses the minimum number of cooling units to reduce investment costs.

(ii). Thermal Comfort Optimization: Arranges the devices evenly to ensure uniform temperature distribution.

User Options: The program offers multiple layout options and allows users to choose the one that best meets the design requirements.

- Step 4: Data Input and Automatic Layout Execution

The algorithm automatically matches room data, calculates the total required cooling capacity, selects the appropriate device model, and places the units within the Revit model. The automatic placement follows these criteria:

+ Distance from Walls: At least 1.5m away from the wall.

+ Spacing Between Units: Adheres to manufacturer recommendations.

+ Total Installed Capacity: Must not be lower than the calculated cooling load for each room.

Additional feature: The tool also integrates a cost estimation function that provides a preliminary report on the total investment cost for the cassette-type indoor units in each layout option. This feature helps designers make decisions that align with both technical requirements and the project budget.

2.2. Mathematical models and CFD simulation equations

The CFD simulation model was established for an office space measuring 3.7 m × 7.3 m × 3 m (approximately 27 m²), using a 4-way ceiling cassette unit with a total cooling capacity of 5.6 kW. The simulation aims to analyze temperature and airflow distribution within the room to evaluate thermal comfort levels.

The model was constructed and simulated using ANSYS Fluent 2025 R1 software, applying the Finite Volume Method (FVM) and the RNG k–ε turbulence model to solve the time-averaged Navier–Stokes equations under three-dimensional, steady, incompressible, and turbulent flow conditions.

The meshing process is performed using the Mesh tool, combining two types of Tetrahedron and Hexahedron elements to ensure mesh quality and limit element deformation. The model uses a total of 1,032,780 mesh elements. The mesh quality was evaluated as meeting technical standards with a Maximum Skewness of 0.795 (rated as "Good") and an Orthogonal Quality of 0.996 (rated as "Excellent"), according to ANSYS

Fluent's recommendations. Additionally, the model underwent a mesh independence check, confirming that the simulation results were not affected by the mesh structure.

The boundary conditions were defined to realistically simulate thermal and airflow behavior within the room. The supply vent (inlet) of the Cassette-type indoor unit was set as a velocity-inlet with a velocity of 1.5 m/s and temperature of 20 °C, while the return vent (outlet) was defined as a pressure-outlet at 27 °C. Internal heat sources, including lighting (52 W/m², emissivity 0.85), computers (180 W/m², emissivity 0.90), and human occupants (60 W/m², emissivity 0.98), were modeled using wall boundary conditions with specified heat flux values. The external wall exposed to solar radiation was treated with a radiation boundary condition, using an emissivity of 0.85 and an external radiation temperature of 35°C.

The Coupled solution algorithm was chosen to enhance convergence performance, combined with the Second Order Upwind discretization method to increase simulation accuracy on triangular and tetrahedral meshes. The convergence criterion was evaluated through Scaled Residuals, with values ranging from 10^{-3} to 10^{-7}, indicating that the model reached a stable state and that the simulation results are highly reliable.

Governing Equations Applied:

- Continuity Equation

The governing equations applied include the continuity equation, which states that the mass entering and exiting a system must be equal.

$$\frac{\partial \rho}{\partial t} + \nabla(\rho \vec{v}) = 0 \quad (1)$$

Where: ρ (kg/m³) is density, t(s) is time, $\vec{v}$ is flow velocity vector.

- Momentum Equation

The Law of Momentum Conservation (Newton's Second Law) states that the magnitude of the external force acting on a fluid particle equals the rate of change of linear momentum.

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j) = \frac{\partial}{\partial x_j}\left[-\rho\delta_{ij} + \mu\left(\frac{\partial u_i}{\partial x_i} + \frac{\partial u_j}{\partial x_j}\right)\right] + \rho g_i \quad (2)$$

Where: j (m): Cartesian coordinate index; δ: the Kronecker Delta; μ ((N. s)/m²): dynamic viscosity; g (m/s²): gravitational acceleration.

Combining the equations in the x, y, and z directions yields the comprehensive Navier-Stokes equation:

$$\rho\frac{\partial \vec{u}}{\partial t} = \rho\left(\frac{\partial \vec{u}}{\partial t} + \vec{u}.\overrightarrow{\nabla u}\right) = \rho g - \nabla p + \mu\nabla^2\vec{u} + \frac{1}{3}\mu\nabla(\nabla.\vec{u}) \quad (3)$$

Using kinematic viscosity ν= μ/ρ, the equation becomes:

$$\frac{\partial \vec{u}}{\partial t} = \frac{\partial \vec{u}}{\partial t} + \vec{u}.\overrightarrow{\nabla u} = \vec{g} - \frac{1}{\rho}\nabla p + \mu\nabla^2\vec{u} + \frac{1}{3}\mu\nabla(\nabla.\vec{u}) \quad (4)$$

- Energy Equation

$$\frac{\partial}{\partial t}(\rho e) + \nabla.[(\rho e + p)\vec{v}] = \nabla\left[k_{eff}\nabla T - \sum_j h_j.\vec{J_j} + (\overrightarrow{\tau_{eff}}.\vec{v})\right] \quad (5)$$

3. Results and Discussion

3.1. Development of BIM Tools for Automatic Cassette Air Conditioner Layout and Experimental Application

3.1.1. Development of BIM Tools for Automatic Cassette Air Conditioner Layout

Currently, there are various types of indoor units on the market; this study selects cassette-type units due to their prevalence and compatibility with the BIM tool's objectives in automated layout and temperature simulation.

The developed tool operates directly on the Autodesk Revit platform, automating the HVAC system design process from input data entry, cooling load calculation, to equipment layout. With an intuitive and straightforward interface (Figure 2), users can easily perform basic configuration operations.

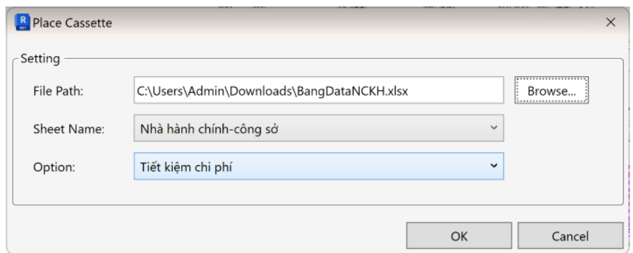

Figure 2. *Main interface of BIM Tools for automatic cassette air conditioner layout*

The BIM tool usage process begins by selecting the input data file via the "File Path" section, where users browse and upload an Excel file containing room lists, calculated cooling loads, and a catalog of preconfigured equipment. All data in the Excel file have been pre-calculated by the researchers and verified using reputable cooling load calculation software, ensuring the reliability of the figures. After selecting the Excel file, in the "Sheet Name" section, users choose the relevant data table from the available sheets. Additionally, the building type is selected to determine the appropriate design parameters for the ongoing project.

After setting the input data, the program automatically scans the Revit model and matches "Room" objects whose "Name" attribute matches the room names in the Excel table. From there, the tool collects detailed information on each space to calculate the minimum cooling capacity required for each room.

Based on the cooling load data and building type, the program suggests design options in the "Option" section. Each option includes the number and capacity of cassette air conditioners suitable to meet the required cooling load. The device placement is determined automatically, ensuring technical requirements such as minimum distance from the wall and spacing between units according to manufacturer standards.

After the user selects the desired design option, the program runs the layout algorithm based on the chosen cooling capacity and design criteria, thereby automatically embedding the air conditioners into the BIM model in an accurate and rational manner.

3.1.2. Experimental Application

After completing and testing the BIM tool for automatic cassette air conditioner layout, the research team conducted a practical application on a real project - the Club House building (Figure 3). This project is a large-scale construction with complex architecture and multiple functional spaces, requiring flexible and efficient HVAC system layout to ensure optimal energy usage. The application of the tool in this project aims to evaluate its adaptability, accuracy in device arrangement, and verify the effectiveness of the algorithm in handling diverse design data within the BIM model.

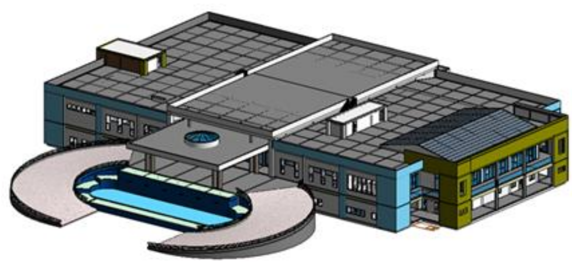

Figure 3. *Overview of the Club House project*

After inputting the design data into the BIM model of the Club House project, the tool automatically scanned the utilized spaces, identified cooling load information, and proposed suitable equipment layout options. Based on the calculation results, the program arranged the cassette air conditioners in functional areas, ensuring technical criteria related to capacity, installation distance, and heat distribution. The floor plan of the equipment arrangement after applying the tool is shown in Figure 4.

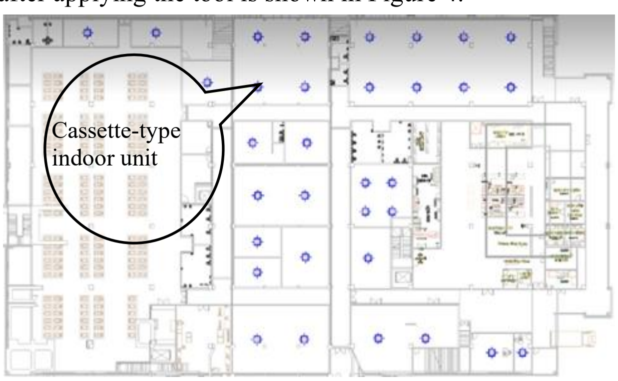

Figure 4. *Floor plan after automatic cassette-type indoor unit layout based on the cost-saving option*

A notable feature of the tool is its ability to calculate and aggregate cost data within a few seconds after completing the automatic cassette air conditioner layout, significantly shortening the time compared to traditional manual methods. Thanks to this feature, users can quickly compare different layout options, grasp the equipment volume and preliminary cost visually, and make design decisions that meet the technical requirements and financial constraints of the project.

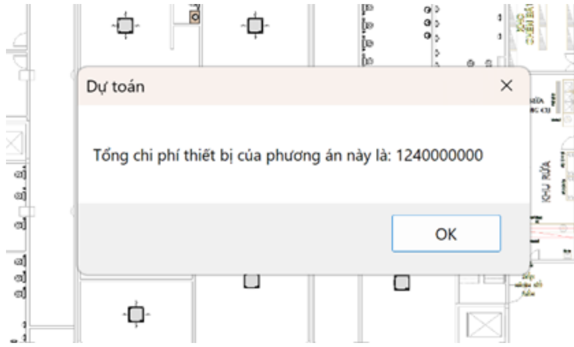

Figure 5. *Cost estimation table for indoor units based on the cost-saving option for the entire project*

The testing of this feature was performed in a typical room with an area of 27 m² to evaluate the effectiveness of the two cassette air conditioner layout options proposed by the tool. In the "Cost-Saving" option (Figure 6), the system automatically selects a 5.6 kW air conditioning unit to meet the calculated cooling load of 4.6 kW. This option fully satisfies the cooling capacity requirement with a low investment cost, suitable for spaces that do not require a high degree of even temperature distribution or rapid cooling.

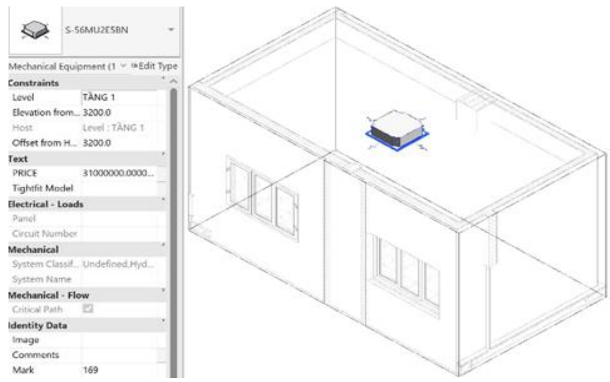

Figure 6. *Cassette air conditioner layout according to the "Cost-Saving" option*

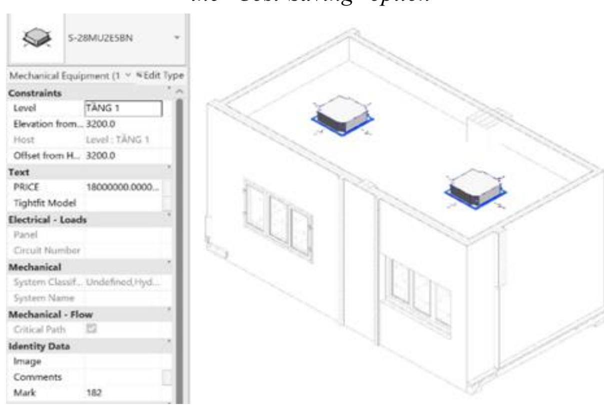

Figure 7. *Cassette air conditioner layout according to the "Comfort Condition" option*

Meanwhile, the "Comfort Condition" option (Figure 7) suggests using two air conditioning units of 2.8 kW each, arranged at an suitable distance to enhance airflow distribution efficiency. Although the total capacity is equivalent, this option improves fast and uniform cooling in the space, suitable for areas requiring higher comfort standards. However, the initial investment cost will be higher due to the increased number of units.

The test results show that each option offers distinct advantages: the "Cost-Saving" option is suitable for projects prioritizing low initial investment costs, while the "Comfort Condition" option better meets cooling efficiency requirements. Therefore, selecting the appropriate option depends on the specific design objectives of each project.

3.2. Temperature distribution simulation in the room

After the cassette air conditioners were automatically arranged in the Revit model, the temperature distribution and airflow velocity simulation results were obtained using the Ansys Fluent software. The purpose was to evaluate the effectiveness of the design options.

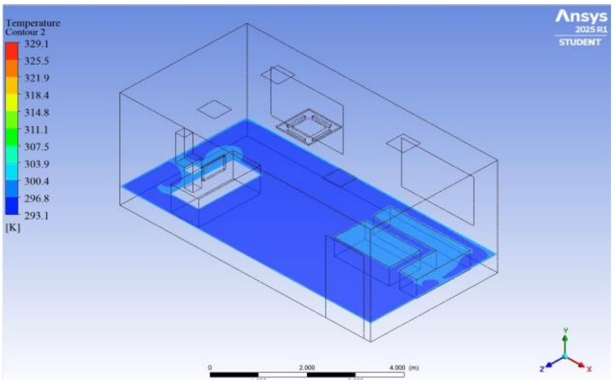

Figure 8. *Temperature field at a height of 0.6 m*

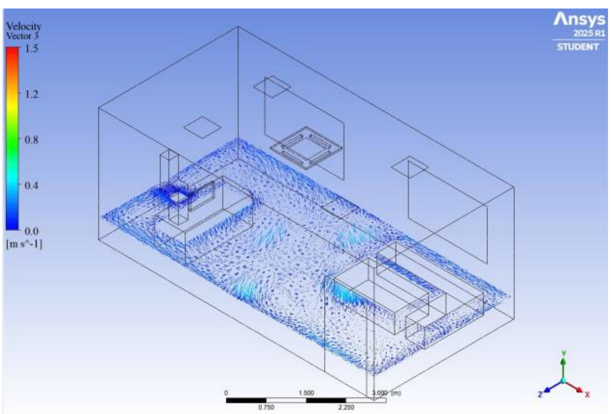

Figure 9. *Air velocity field at a height of 0.6 m*

The simulation results shown in Figures 8 and 9 illustrate the temperature and airflow velocity distribution in the room at a height of 0.6 m, where users can directly perceive the thermal conditions. At this height, the temperature ranges from 23°C to 25°C, and the airflow velocity varies from 0.1 m/s to 0.5 m/s.

Based on the temperature and airflow distribution results shown in Figures 8 and 9, the research team programmed the PC-BASIC software to calculate the PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) indices to assess user comfort in the air-conditioned environment. The calculation results indicate:

- The PMV index suitable for most people ranges from -2 to +2 [5]. The calculated PMV value of -0.8, situated between (-1) - slightly cool and (0) - neutral, falls within the acceptable range, indicating that most users would feel comfortable with the room temperature.

- The PPD index, evaluated according to ASHRAE 55 [6] and ISO 7730 [5] standards, is considered appropriate when below 20%. The calculated PPD value of 16.9% means that 16.9% of users would feel uncomfortable with the temperature. This result is within the permissible limit, meeting the requirements.

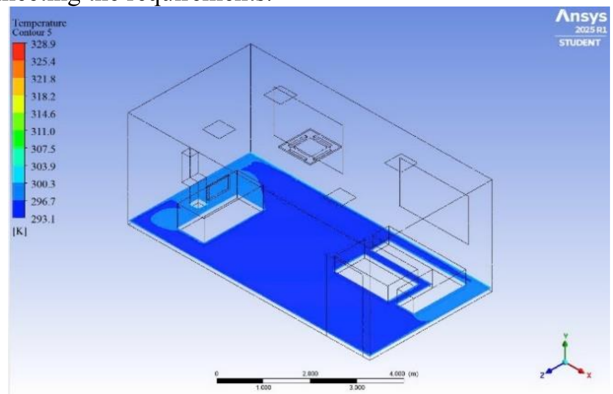

Figure 10. *Temperature field at a height of 0.1 m*

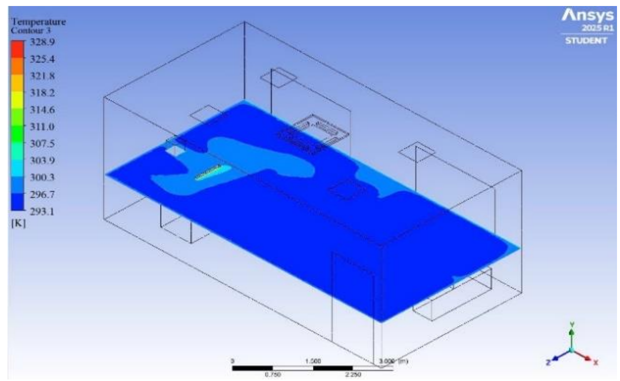

Figure 11. *Temperature field at a height of 1.1 m*

Additionally, to comprehensively assess the thermal comfort conditions in the room, other indices such as draft rate (DR) and temperature difference according to body height (VATD) were also examined. The calculation results are as follows:

- The calculated DR index at a height of 0.6 m is 4.93%, within the allowable limit (below 15% [5]). Therefore, people working nearby will not be affected by cold air from the supply vent.

- The abnormal temperature difference according to body height (VATD) between the head and ankles can cause discomfort and increase the risk of health issues. To ensure thermal comfort and health, the temperature difference should not exceed 3°C [5]. Looking at the temperature field in Figures 10 and 11, the maximum temperature difference is only about 2.3°C, within the allowable limit, ensuring comfort and safety for users.

Thus, the Ansys Fluent simulation demonstrates that the cassette air conditioner layout using the developed BIM tool in the BIM model meets the thermal comfort requirements.

The temperature field shown in Figure 12 indicates that the air temperature within the room space ranges from 20°C to 26°C. The lowest temperature is recorded near the air outlet, where cold air is directly distributed into the room. In contrast, the highest temperature of about 55°C appears near the heat-generating device (laptop). As the workspace is positioned among surrounding corridors and air-conditioned rooms, the room's temperature field is influenced by the thermal characteristics of the enclosing structure, and the primary heat sources are human activities and equipment.

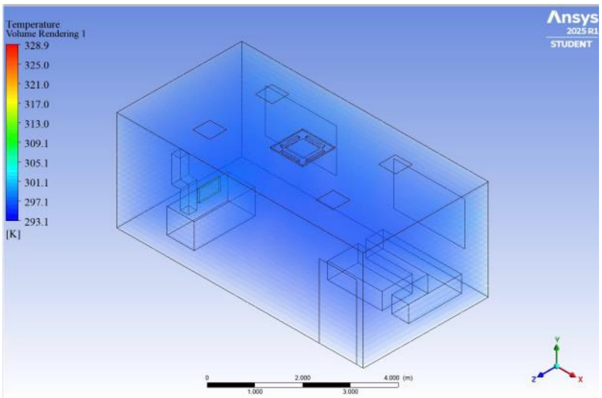

Figure 12. *Temperature distribution in the room*

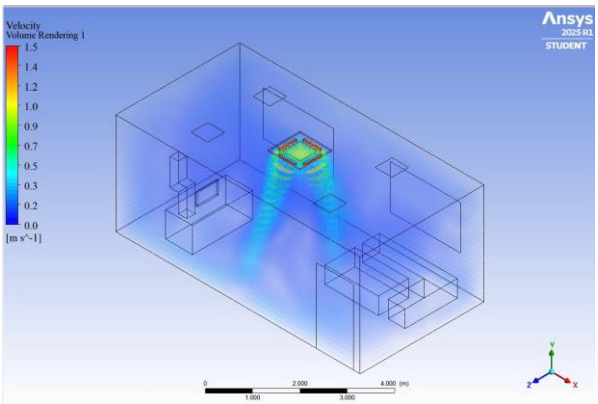

Figure 13. *Air velocity distribution in the room*

Airflow movement within the room appears relatively stable and evenly distributed. The air velocity distribution (Figure 13), ranging from 0.1 m/s to 1.5 m/s, ensures uniform air distribution, creating a comfortable and pleasant environment for users. This distribution helps maintain an ideal workspace and living environment.

4. Conclusion

This study successfully developed and integrated a BIM tool that supports the automatic layout of cassette air conditioners within the Autodesk Revit environment, combined with CFD simulation using ANSYS Fluent software to evaluate thermal comfort effectiveness in air-conditioned spaces. The tool was built using the C# programming language on the Revit API platform, allowing the import of design data from Excel, cooling capacity determination, equipment selection, and layout according to predefined technical standards. The test results demonstrate that the tool significantly reduces design time, increases accuracy, and supports rapid investment cost estimation.

Verification of the design options through CFD simulation shows that the temperature and airflow distribution within the space achieve thermal comfort indicators according to international standards (PMV, PPD, DR, VATD), confirming the solution's effectiveness and reliability. As a result, this study contributes to demonstrating the potential integration of geometric design (BIM) and technical analysis (CFD) within the modern HVAC system design process.

However, the current tool still has some limitations. The layout algorithm does not optimize the cooling capacity individually for each device within each space, leading to errors in some complex cases. In addition, operating the tool and performing CFD simulations require relatively high computer specifications, posing challenges for widespread adoption in smaller units or in conditions with limited hardware capabilities.

In the future, the research team aims to improve the algorithm to optimize cooling capacity, minimize errors, and enhance system performance. Furthermore, expanding compatibility with various types of equipment and different projects will increase the tool's flexibility and commercialization potential. In addition, integrating artificial intelligence (AI) to predict thermal loads based on environmental data or usage behavior is also a promising development direction, contributing to enhancing the intelligence and practical application of the solution in the construction industry.

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