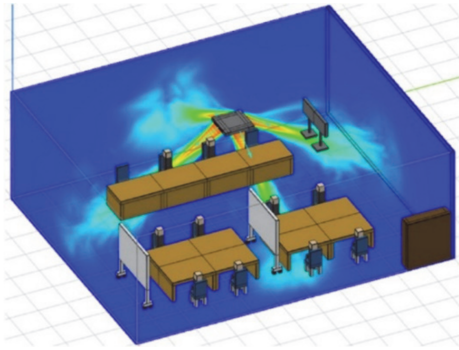
User-friendly and Fast Indoor and Outdoor Thermal Fluid Simulator Using GPU Cloud Computer



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Comfort and energy efficiency of air-conditioning equipment is dependent on the three-dimensional flow in the area where the equipment is installed. On the other hand, selection and layout design of air-conditioning equipment are mainly carried out using one-dimensional heat load calculations, and three-dimensional airflow and temperature simulations are not widely used because it requires height level expert knowledge, high cost, and a large amount of time to use. Mitsubishi Heavy Industries, Ltd. has developed an easy-to-use GPU cloud simulator that can rapidly calculate airflow and temperature. With this cloud simulator, even first-time users can model a typical office conference room in about 20 minutes and complete the simulation in about 3 minutes. Furthermore, when the test results were compared with the predicted results, the practical accuracy of the developed cloud simulator could be confirmed. Consequently, a comfortable air-conditioned environment can be created using this simulator.

1. Introduction

In recent years, energy savings, in addition to improvement in the living and working environments, has been demanded, and comfortable air-conditioning is an important environmental factor in daily life and work, along with noise and lighting. Accordingly, facility users and owners desire indoor unit layouts that provide comfortable spaces with the greatest possible energy savings and outdoor unit layouts that do not cause a short-circuit.(*1) However, equipment selection and layout design of air-conditioning equipment are generally performed by the construction and design company based on air-conditioning equipment specifications and one-dimensional heat load calculations.

Detailed information regarding distribution of airflow and temperature in an air-conditioned environment can be determined by simulation of airflow and temperature in the area. Therefore, thermal and fluid simulator makes it possible to select the appropriate air-conditioning equipment and layout design in consideration of indoor and outdoor placement of such equipment. However, since few people have the skills to handle three-dimensional simulations of airflow and temperature and the simulation itself requires a lot of time and effort, selection of the air-conditioning equipment and layout design using three-dimensional simulation of them is rarely performed. There is room for improvement in the method of selection and layout design of air-conditioning equipment for indoor and outdoor units.

Mitsubishi Heavy Industries, Ltd. (hereinafter referred to as MHI) has developed an airflow and temperature simulator that can easily create simulation models and perform high-speed calculations. This report presents an overview of the developed simulator and verification results of its accuracy by a comparison of the test results.

*1 Short-circuit of an outdoor unit refers to a phenomenon in which airflow from the outlet of the outdoor unit flows directly into the suction inlet. When this occurs, the substantial inflow rate of the outdoor unit decreases, reducing capacity and lowering air-conditioning capacity of the indoor unit (the room cannot be cooled/warmed sufficiently).

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2. Overview of developed simulator

2.1 Features of typical three-dimensional airflow and temperature simulators

Procedures to use a typical three-dimensional airflow and temperature simulator is shown in **Figure 1**. The first step for a three-dimensional simulation of airflow and temperature is to install the simulation software on a PC. The user must read the installation manual and download the installer. This task (installing software on a PC) requires knowledge of PCs and servers. In addition, simulation operations require experience and skill. Beginners often face problems such as not being familiar with modeling, how to correct mesh generation failures, set up the simulation, and operate the visualization process. Thus, preparation and use of a thermal fluid simulator are not easy, and even in companies engaged in air-conditioning design, few personnel in the development, research, and other departments can handle three-dimensional simulation of airflow and temperature software. Most airflow and temperature simulators on the market are designed to handle general-purpose problems. While they have the advantage of high functionality, they also have disadvantage of long-term training of users before practical application can be achieved.

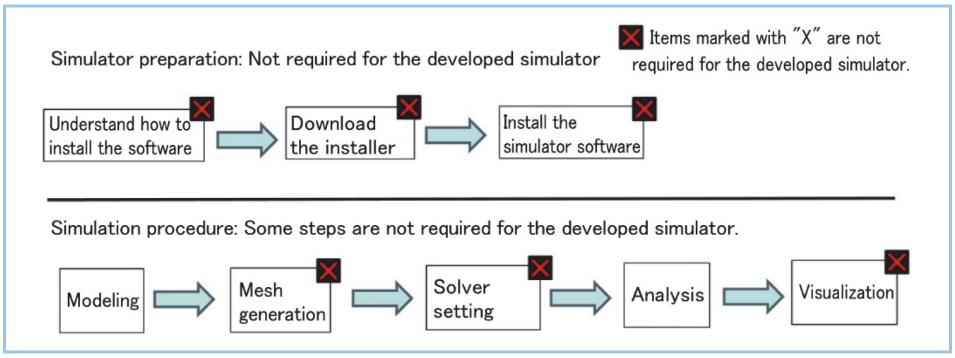

Figure 1 Procedures to use typical three-dimensional airflow and temperature simulator

2.2 How to use developed simulator

The developed simulator presented in this report only requires creating a simulation model. The graphical user interface (GUI) of this simulator is shown in **Figure 2**. Since the WEB application can be started and utilized by the WEB browser, no installation is necessary. This simulator specializes in three-dimensional simulations of airflow and temperature around air-conditioning equipment, greatly reducing the number of operations generally required for simulation and can be used by users intuitively.

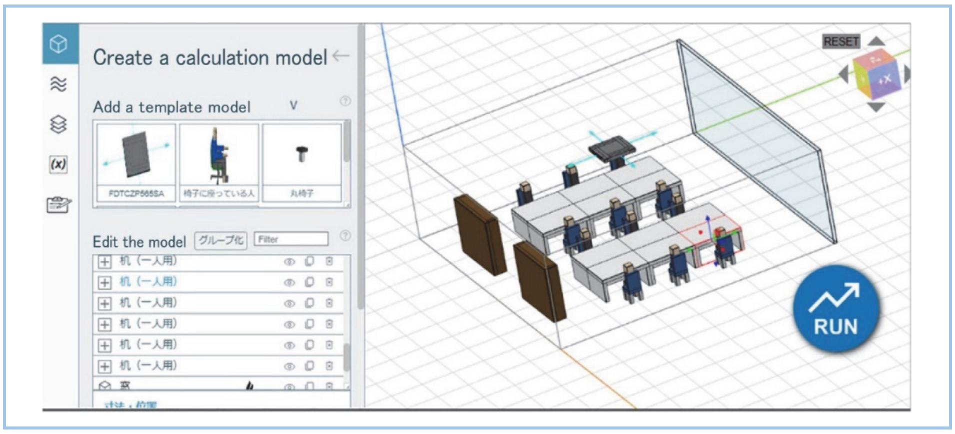

Figure 2 Simulator GUI

The developed simulator allows users to create simulation models in a game-like manner by placing multiple rectangular objects with the mouse and setting attributes such as flow velocity, blowing temperature and suction pressure on each surface of each object to model equipment and furniture. By preparing template models of air-conditioning equipment, furniture and people and libraries of commonly used areas such as offices and outdoor spaces around outdoor units (**Figure 3**), even first-time users can create a typical office model in about 20 minutes. User operations such as mesh generation, simulation setup, and visualization are not required, and calculation can be initiated simply by pressing the analysis execution (RUN) button. After displaying the results of intermediate calculations, the final calculation results are automatically displayed in about three minutes. For a conventional three-dimensional airflow and temperature simulator, even when operated by a skilled worker, it takes at least one day to create a simulation model and generate the mesh before starting the simulation, as well as one hour to perform calculations. In contrast, the developed simulator is extremely simple and fast.

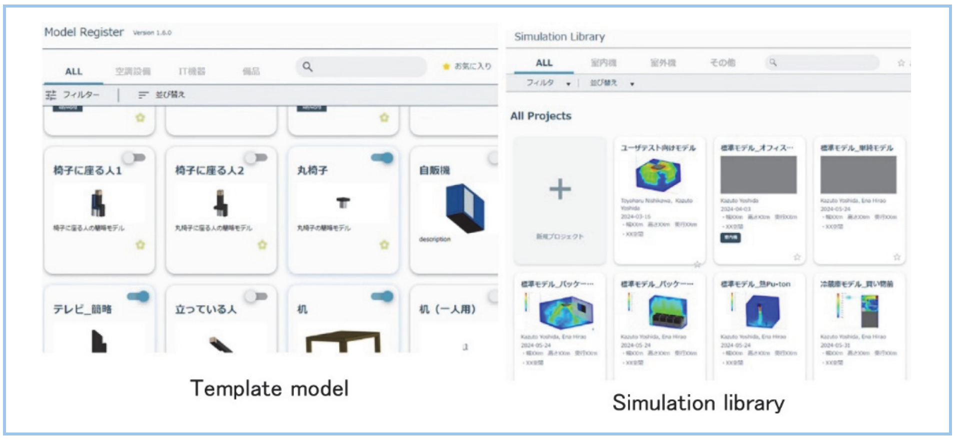

Figure 3　Template model and simulation library

2.3　System configuration

MHI has been developing fluid simulation technology using the lattice Boltzmann method since 2014, WEB application integration platform technology called NECOSYSTEM® since 2017, and heat transfer simulation technology using the finite volume method since 2021. The developed airflow and temperature simulator could be achieved by integrating these component technologies.

Overall system configuration is shown in **Figure 4**. The developed simulator is based on the API (application programming interface) integration of various WEB applications constructed on NECOSYSTEM®. The simulation model created by the GUI is sent to the GPU calculator of the cloud computer via HTTPS transmission, and calculation results are sequentially processed and stored in the database. Calculation results can be shared by URL and the airflow and temperature analysis solver works using container virtualization technology. The system can be easily expanded as the number of users increases.

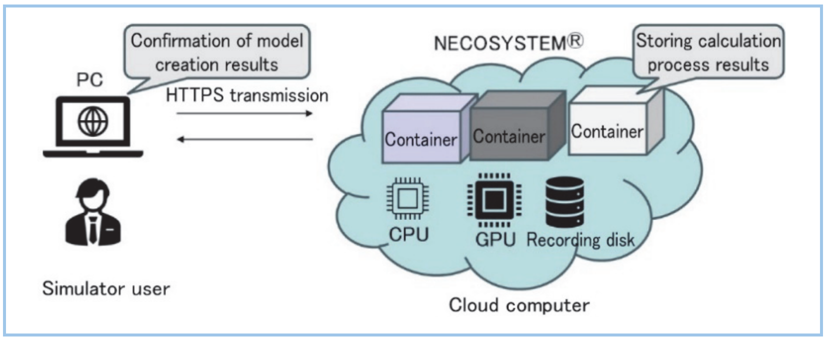

Figure 4　System configuration

2.4　Example of implemented calculations

An example of airflow and temperature calculations using the developed simulator is shown in **Figure 5**. In the simulation of a conference room, the FDT series ceiling-mounted cassette type air-conditioner manufactured by Mitsubishi Heavy Industries Thermal Systems, Ltd. (hereinafter referred to as MTH) is installed and AirFlex®(*2)[1,2] is operated. It was confirmed that the developed simulator could reproduce the air volume that flows along the ceiling and does not directly hit the conference participants seated in the conference room. In addition, in the simulation of the outdoor unit by the developed simulator, an outdoor unit arrangement that prevents short circuits was simulated, and reproduction of airflow conditions where a short circuit due to an upward airflow does not occur could be confirmed.

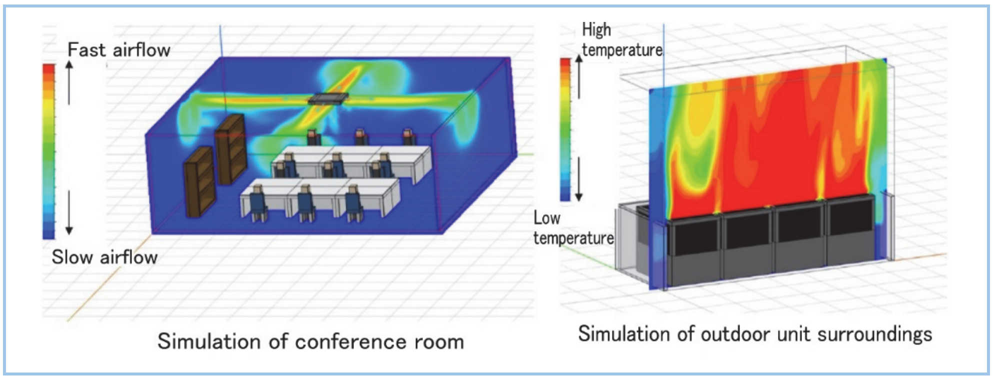

Figure 5 Simulation example

*2 AirFlex is a mechanism developed by MTH that diverts air currents from directly blowing on people, causing them discomfort.

3. Analysis method for airflow and temperature

An analysis method that combines airflow analysis using the lattice Boltzmann method and temperature analysis using the finite volume method was developed. The developed method incorporates various measures for stable and fast calculation and uses a GPU as a calculation resource, resulting in an extremely stable and fast simulator. This simulator can analysis an area of the size of an office conference room in approximately 3 minutes.

3.1 Airflow analysis method (lattice Boltzmann method)

The lattice Boltzmann method does not directly solve Navier-Stokes equations, which are governing equations for a fluid, but represents the fluid as a distribution of virtual particles with a finite number of velocities, and calculates equations of particle streaming and particle collision in each time step for time evolution. The features and advantages of the lattice Boltzmann method developed here(3),(4) are shown in **Table 1**.

Table 1 Features and advantages of the developed fluid analysis method

Feature	Advantage
D3Q27 Velocity Model + Interpolated Bounced Back	High-precision handling of curved surfaces
Equilibrium wall model	Wall resistance is reproduced even on coarse meshes
Volume penalization method	Represents pressure loss objects Fluid drive by external force
Multi-block lattice (Building cube method)	Subdivides meshes only when necessary
Artificial sound velocity	Increases calculation speed
GPU-based calculation	Increases calculation speed

3.2 Temperature analysis method (finite volume method)

The temperature distribution in the simulated area is obtained by solving the thermo-fluid equation using the finite volume method for flow velocity obtained by the lattice Boltzmann method. In order to perform fast and stable calculations, various measures are taken, such as using a pseudo-steady-state method, determining the Courant number according to the flow velocity in the calculation domain and increasing the Courant number as the calculation step progresses, and using the GPU to solve the simultaneous linear equations with an algebraic multigrid method.

4. Accuracy verification

An example case where the air-conditioning inside a room with a residential air-conditioner is analyzed by the developed method is presented in this chapter. MHI has an environmental test facility for testing air-conditioned environments. The facility has a double structure where a studio room is built inside the thermostatic room. A case where a studio room heated by MTH Residential Air-conditioner SRK4023S2 is analyzed.

In the studio room targeted for analysis, thermocouple temperature sensors are placed at equal intervals to measure the temperature distribution in the space as shown in **Figure 6**. Analysis results are shown in **Figure 7**. By comparing the temperature analysis results and the test results, a prediction error of ±1°C for 50% of the area and ±2°C for 80% of the area were obtained. This confirmed that the developed analysis method can predict an indoor air-conditioned space with practical accuracy.

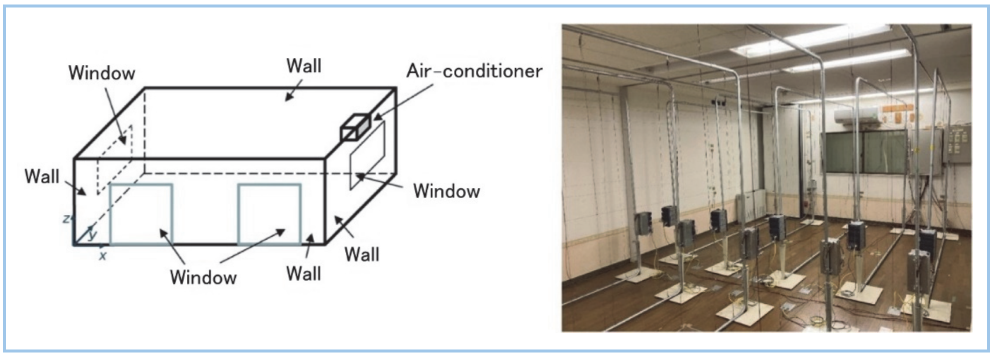

Figure 6　Analyzed room with residential air-conditioner

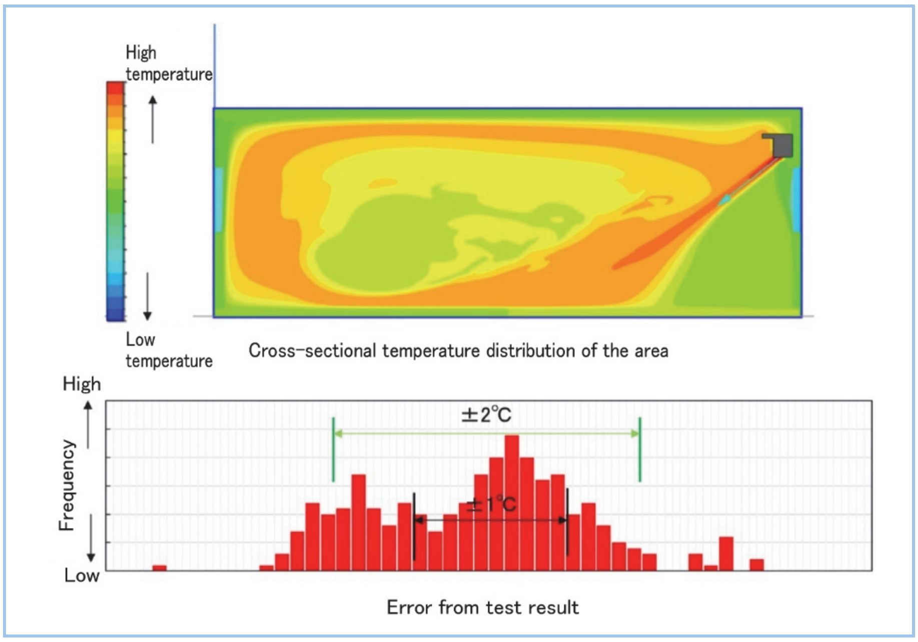

Figure 7　Residential air-conditioner analysis results

5. Conclusion

In recent years, energy savings, in addition to improvement in the living and working environments, has been demanded, and comfortable air-conditioning is an important issue, along with proper lighting and noise control. However, since conventional three-dimensional simulations of airflow and temperature based on three-dimensional thermo-fluid analysis of the air-conditioned environment requires time and effort, model selection and layout design of air-conditioning equipment are often based on equipment specifications and one-dimensional heat load calculations. There is still room for improvement.

With this background, a GPU cloud simulator that calculates indoor and outdoor airflow and temperature on NECOSYSTEM®, an online application common platform, was developed. By integrating three-dimensional analysis technologies of fluid and heat transfer previously developed and WEB application technology, and by creating a simulator specializing in analysis of the environment surrounding the air-conditioning equipment, an easy-to-use simulator operated in a game-like manner that can achieve high-speed calculation performance could be developed. In addition, by comparing the simulation results with temperature measurements taken at MHI’s environmental test facility, the practical accuracy of the simulator could be confirmed. Simulating a comfortable air-conditioned environment, that considers the spatial arrangement of air-conditioning equipment and facilities, has become possible.

MHI will continue to develop simpler simulation models and high-speed simulations in order to recommend the optimal air-conditioner models and layout while maintaining good communication with its customers. MHI will also utilize its developed technology in order to propose the best air-conditioner model selection and equipment layout to its customers and contribute to the creation of an energy-efficient and comfortable air-conditioned environment.

NECOSYSTEM® is a registered trademark of Mitsubishi Heavy Industries, Ltd. in Japan.
AirFlex® is a registered trademark of Mitsubishi Heavy Industries Thermal Systems, Ltd. in Japan.

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