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A Study of Heat Transfer Simulations Using OpenFOAM for Air-Conditioning Guidance System

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Abstract: Currently, we are developing the air-conditioning guidance system (AC-Guide) to optimize the use of the air conditioner (AC) in the room using the indoor/outdoor discomfort index (DI). AC is utilized to offer a thermally comfortable environment for inhabitants in the room. For the proper guidance, the accurate estimation of indoor environmental changes due to on/off of AC and/or opening/closing of windows/doors is very important. In this paper, we study heat transfer simulations using *OpenFOAM* to estimate indoor environmental changes for AC-Guide. We compare the simulation results with measured data in a room at the 3rd floor of Okayama Engineering #2 and confirm the sufficient estimation accuracy.

1. Introduction

Nowadays, houses, schools, factories, and offices are equipped with an air conditioner (AC), to offer comfortable environments for inhabitants and devices/machines in the room. The ideal temperature indoor is critical for people to have healthy and active life, and for devices or machines to function smoothly. Particularly, with the escalation of the global warming, the importance of AC has been highlighted around the world. Previously, we have proposed the air-conditioning guidance system (AC-Guide) for optimal use of AC [1] considering the indoor/outdoor discomfort index (DI). It avoids both the overuse and underuse of AC to save the energy while satisfying the QoL (quality of life).

OpenFOAM is a popular[2], free, open-source computational fluid dynamics (CFD) software. OpenFOAM can simulate various phenomena such as chemical reactions, turbulences, and heat transfers. CFD simulations can help predict heat transfers in the indoor environment in details neumerially.

In this paper, we study heat transfer simulations using OpenFOAM to estimate indoor environmental changes for AC-Guide. We compare the simulation results with measured data in a room at the 3rd floor of Okayama Engineering #2 and confirm the sufficient estimation accuracy.

In [3], Shan et al. compared CFD simulation results with measured results using the FCU system in an office room in Hong Kong and evaluate the PMV value in their research.

In [4], Laitinen et al. study the liquid cooling heat exchanger is carried out using the open source computational fluid dynamics (CFD) library OpenFOAM. It can effectively help them understand how parameters change such as pressure, velocity.

The rest of the paper is organized as follows: Section 2 reviews AC-Guide. Section 3 presents the simulation model for OpenFOAM. Section 4 discusses experiment results. Section 4 concludes this paper with future works.

2. Overview of air-conditioning guidance system

The AC-Guide periodically monitors the conditions in the room such as temperature, humidity, CO_2 density, on/off state of AC, and opening/closing state of windows/doors. Then, it calculates DI and sends the message of requesting turning on/off the AC based on it. The prototype system of AC-Guide was implemented using Raspberry Pi 3 model b+ with Python programs. Figure 1 illustrates the overview of AC-Guide.

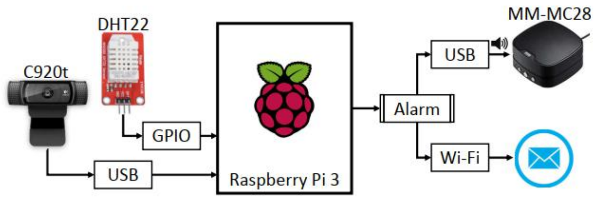

Figure 1 System Overview

3. OpenFOAM simulation model

To estimate indoor environmental changes by calculating heat transfers using OpenFOAM, the full-scale model for one room at the 3rd floor of Okayama Engineering #2 was made as shown in Figure 2.

Table 1 Patterns of Simulation

pattern	windows	AC	ventilation	lights
1	no	no	no	no
2	no	yes	no	no

Table 1 shows the simulation conditions. For each pattern, different boundary conditions are prepared, and the simulation results are compared with the measured data, to confirm the estimation accuracy.

The size of the room model is 6.8m × 6.15m × 2.65m. It has one external wall with four windows and three internal walls without windows. Two ACs are mounted on the ceiling. Each AC has four outlets with

45° degree. The temperature sensor was placed at the white dot place Figure 2, which is the student's chair at the corner of the room close to the window. The sensor possesses the accuracy of ±0.5 ℃ varying from -40℃ to 60℃ and the sampling interval is one minute.

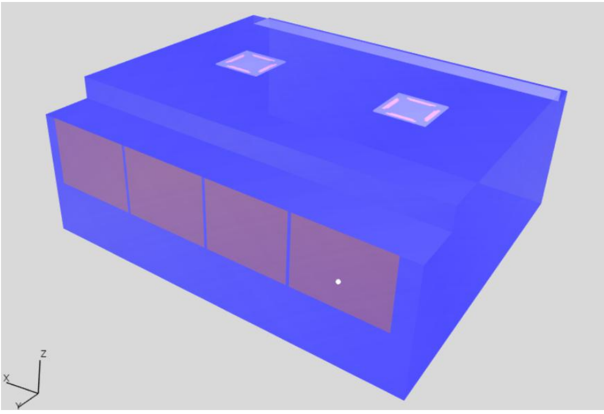

Figure 2 Room Model

4. Experiment Results

First, we use pattern 1 in Table 1 to simulate OpenFOAM and compare the simulation data with the measured data. The data was measured from 0:00 AM to 0:19 AM on Nov. 13, 2021. The outside temperature was 9℃ and the temperature set-point of the room was 19.61℃.

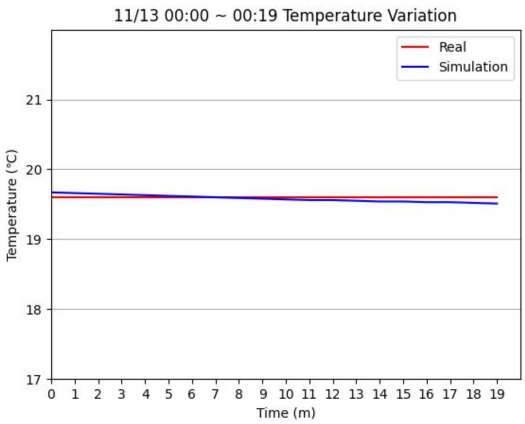

Figure 3 Result of Pattern 1

Figure 3 shows the simulation data and the measured data. They indicate that the temperature estimated in the simulation is matched well with the experimental data, where the largest temperature difference between them is about $\Delta t_{max} = 0.1$℃ in 19 minutes.

Next, we use pattern 2. The data was measured from 18:26 to 18:35 on Nov. 18, 2021. The outside temperature was 9℃ and the temperature set-point of the room was 19.61℃. For AC boundary conditions, the airspeed of the outlet was 1.6 m/s and the temperature was 22.6 ℃. Figure 4 shows the temperature results.

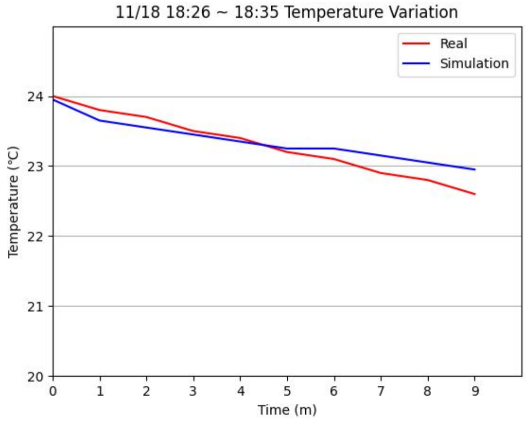

Figure 4 Result of Pattern 2

According to the results, before 4 minutes, the measured data decreased faster than the simulation data. From 4 to 6 minutes, the simulation data was a little bit raised. After 6 minutes, it was decreased again. However, the measured data continued decreasing even after 4 minutes. The maximum difference between the simulation data and the measured data was about $\Delta t_{max} = 0.35$℃ in 9 minutes.

5. Conclusion

This paper studied heat transfer simulations using OpenFOAM to estimate indoor environmental changes for AC-Guide. The simulation results were compared with the measured data in a room at the 3rd floor of Okayama Engineering #2 and the estimation accuracy was confirmed. In the future, we will evaluate the simulation model by measuring data for different patterns and seasons.

Reference

[1] M. Sakagami, N. Funabiki, Y.-Z. Huo, K. Kojima, and W.-C. Kao, "A study of ventilation guidance function in air-conditioning guidance system," in Proc. ICCE 2022, Jan. 2022.

[2] OpenFOAM, "OpenFOAM Information," https://www.openfoam.com/

[3] X. Shan, W. Xu, Y. K. Lee, and W. Z. Lu, "Evaluation of thermal environment by coupling CFD analysis and wireless-sensor measurements of a full-scale room with cooling system," Sust. Citi. Society, vol. 45, pp. 395-405, Feb. 2019.

[4] Laitinen, A., Saari, K., Kukko, K., Peltonen, P., Laurila, E., Partanen, J. and Vuorinen, V., 2020. A computational fluid dynamics study by conjugate heat transfer in OpenFOAM: A liquid cooling concept for high power electronics. International Journal of Heat and Fluid Flow, 85, p.108654.