A new approach to couple building energy simulation with CFD by means of CRI (contribution ratio of indoor climate)

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SUMMARY

By coupling the contribution ratio of indoor climate (CRI), which is based on CFD, with the energy simulation tool, such as TRNSYS or EnergyPlus, a more accurate energy simulation for non-uniform indoor thermal environment could be expected. In this study, the concept of CRI is introduced, and an approximation method on heat transfer analysis and the approach of integrating network model and CRI is introduced.

Keywords: Contribution ratio of indoor climate (CRI), computational fluid dynamics (CFD), energy simulation, dynamic integration, TRNSYS

INTRODUCTION

Generally, the tools whose primary function is to simulate the energy performance of a building, known as energy simulation programs such as DOE-2, EnergyPlus or type56 of TRNSYS (Hong, 2000), are based on network model. In the case of network model, it is assumed that the air in the indoor space is well mixed, so temperatures of rooms and zones are uniform.

Recently, the systems with non-uniform temperature distribution, such as the task ambient air-conditioning system, are widely utilized for their advantage of positively using the air current and temperature distribution to efficiently control the room air temperature in living space. For this case, a higher cumulative error in energy simulation may occur if the temperature distribution is not considered.

For this problem, an approach of integrating CFD and network model is proposed in this research to analyze the energy consumption of indoor space with non-uniform temperature distribution.

CONCEPT OF CRI

Indoor thermal environment is affected by various heat factors, including heat transferred from solid walls, warm or cool air supply from jet openings, hot or cold panels, and heat generations. Although these heat factors have their own characteristics, they all affect the air temperature in the same way warming up or cooling down the air temperature by convection. In this study, all these heat factors are modeled as heat sources of the energy governing equation. If the buoyancy with density variation caused by temperature could be considered to have little effect on air motion, it is assumed that the temperature field in a room can be treated as a linear system, which means a temperature field can be seen as the superimposition of several sub-temperature fields, each of which is dominated by a single heat source.

The index contribution ratio of indoor climate is developed to evaluate how each single heat source affect the structure of the temperature distribution. It was firstly proposed as an index to estimate the individual contribution of each heat factor to the temperature distribution in forced air flow field (Kato, 1994). To make the original CRI available cover more cases, a new definition of CRI is proposed in this study. When calculating CRI, it must make sure that there is only one heat source set in the fixed air flow field to evaluate the individual contribution of this heat source. The CRI of heat source \( m \) at location \( x_i \) is defined as equation (1), that is the ratio of temperature rise from netural temperature \( \theta_n \) and the heat \( Q_m \) released from heat source \( m \). Once the CRIs have been calculated, they can be treated as constant as long as the air flow field is considered not changed. And for the fluctuant heat load, temperature distribution can be predicted by using equation (2).

\[
CRI_m(x_i) = \frac{\theta(x_i) - \theta_n}{Q_m}
\]

(1)
\[ \theta(x) - \theta_s = \sum_C (CRI(x) \cdot Q_n) \]  

(2)

**COUPLING STRATEGY OF CRI AND NETWORK MODEL**

As illustrated in Fig. 1, the air temperature is solved by CRI model. The CRI of each heat source had been calculated in advance based on a fixed represent air flow field. When given the heat fluctuation of each heat source, the dynamic temperature distribution could be obtained.

The module type56 of TRNSYS was introduced as the network model in this study, and a thin space near each wall is divided as an independent air node. The air temperatures of these zones are read from CRI model to directly solve the energy balance equation of surface without iteration between CRI model and the type56 of TRNSYS to reduce the computing load. In this way, the heat transfer to indoor air can be obtained. This will be used as one of the input conditions to CRI model to determine the temperature distribution for next time step.

In the traditional energy simulation, for calculating the thermal load, a cooling or heating option must be activated to make the space-average temperature meet a constant temperature require or follow a running schedule. While in the CRI-Network coupling model, heat supply from air-conditioning is not set in the network model, but set as a heat source affecting the temperature distribution. How much heat should be supplied is determined by the required temperature of the target space, such as a task area or living space in office.

**CONCLUSIONS**

The definition and calculation method of contribution ratio of indoor climate (CRI) was introduced, based on which, the coupling strategy of network model and CRI has been introduced. In the future, this study will be continued for applying on real cases, such as office rooms with task-ambient or personal air-conditioning system. Because the CRI is defined based on the assumption of linear temperature field and calculated in fixed air flow field, the confirmation of CRI’s robustness in air flow fields with VAV system or dominated by natural convection is another subject of this study.

**REFERENCES**
