Modelling thermal comfort and energy consumption of a typical mixed-cooling apartment in Guilin, China

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ABSTRACT

Many studies have shown that the use of mixed-mode cooling can bring down the cooling load significantly while maintaining satisfactory in door air quality and thermal comfort. But there is little information available concerning mixed-mode cooling in China. Thus, basing on design parameters of design standard, A series of computer simulation of a typical mixed-cooling apartment in Guilin, lies south-west of China, was conducted by Eneryplus and Climate Consultant software. Analysis of the results indicates natural ventilation can burden part air conditioning load but is not enough to satisfy the requirement of indoor thermal comfort, mechanical cooling and heating systems are needed. For the whole year, the running days of individual natural ventilation, heating and cooling are very seldom, and hybrid operation is available for most of the year. There are difference using Fanger model and adaptive model to assess thermal comfort in mixed-mode spaces. Which one is the most suitable methods need to further research. The current design parameters of fully air-conditioning and natural ventilation buildings can not be simply used in mixed-mode cooling design. People's behaviour in mixed-mode spaces have an major influence to energy consumption. The study will contribute to a deep understanding of thermal comfort and energy consumption of mixed-mode buildings. At the same time, it will also enlighten to optimize suitable design parameters and control strategies of mixed-cooling apartments in south-west of China.

KEYWORDS

Mixed-mode cooling; Apartments; Energyplus; Thermal comfort; Energy consumption

1 INTRODUCTION

Air-conditioning systems for space cooling is responsible for more than half the energy consumption in buildings for Chinese climates. According to statistics, the total building energy consumption in China accounts for 21% of the total national energy consumption (Tsinghua, 2013). Many studies have shown that the use of mixed-mode cooling can bring down the cooling load significantly while maintaining satisfactory in door air quality and thermal comfort(Daaboul, et al., 2018; Barbadilla-Martin, et al.,2018).Mixed-mode cooling refers to a hybrid approach to space conditioning that uses a combination of ventialtive cooling and mechanical cooling that provide air distribution and some form of cooling(Heiselberg, 2002; Brager, 2006). Mixed-mode cooling system has been researched extensively in the University of California, Berkeley. However, to the best of our knowledge, there is little information available concerning mixed-mode cooling buildings in China. Thus, the purpose of this study was to conduct a simulation on thermal comfort and energy consumption in a mixed-cooling apartment in Guilin, lies in hot summer and warm winter zone of China. The building construction for the case, lighting and other inter gains data about the building can be found in the design standard(Ministry, 2003). The study will contribute to a deep understanding of thermal comfort and energy consumption of mixed-mode buildings. At the same time, it will also provide suitable control strategies of mixed-cooling apartments.

2 METHODOLOGY

Guilin city is located in the south-west of China and belongs to the hot summer and warm winter climate zone. The climate data of Guilin city, which was downloaded from Energyplus website (Energyplus, 2019), is analysed using Climate Consultant software version 6.0 to gain knowledge into the mixed-mode design. EnergyPlus is used as the simulation tool in the study for modelling thermal comfort and energy consumption of a typical apartment for a family with three people-parents and one child. EnergyPlus, developed by U.S. Department of Energy, is an open-source whole-building energy simulation program built upon sub-hourly zone heat balance and integrated solutions of building loads, HVAC systems, and central plant equipment. Generally, a typical apartment includes three rooms- a living room, a master room and a secondary room. Figure 1 shows the model of the typical apartment. A multi-zone variable air volume (VAV) system, with a single-speed direct-expansion (DX) cooling coil and a gas burner, is used to provide cooling and heating for the living room and the master room. Natural ventilation is applied to the secondary room. Temperature-based control strategy is used to control mixed-cooling systems**.** EnergyPlus Airflow network is used to simulate airflow movement through multizone wind driven airflows with hybrid ventilation control. Energy management system (EMS) in EnergyPlus is used to implement different control strategies for mixed-mode systems.

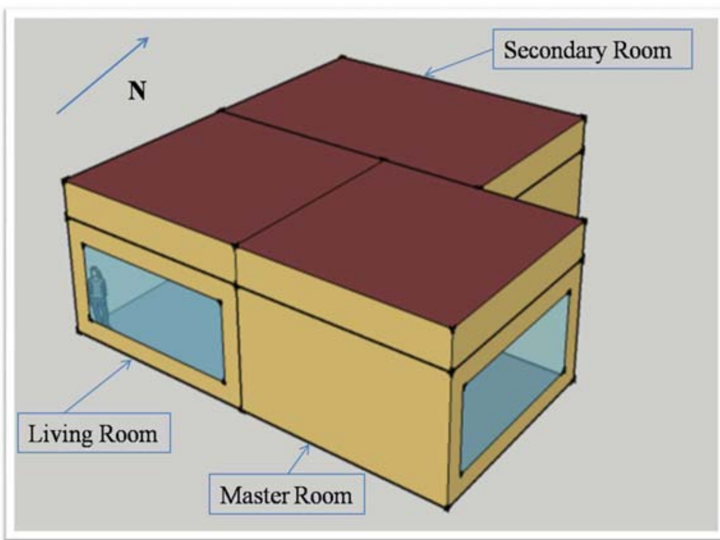

Fig.1 Model of the typical apartment

3 RESULTS AND DISCUSSION

3.1 Climate analysis

The climate data of Guilin is analysed using Climate Consultant software version 6.0 to gain insights into the mixed-mode cooling design. The timetable plot in Fig.2 shows that natural ventilation a day before10:00 a.m. may work in summer months, air-conditioning would be required in the afternoon of summer time and night ventilation with thermal mass may work in the summer and transition months. The psychrometric chart in Fig. 3 shows that different design strategies are utilized to available thermal comfort. The main measures under the weather conditions include adaptive comfort ventilation (28.2%), heating with dehumidification (25.3%) ,internal heat gain(23.6%), and dehumidification only(20.9%), which also indicate that natural ventilation is not enough to conditioned the temperature, mechanical cooling and heating systems are needed.

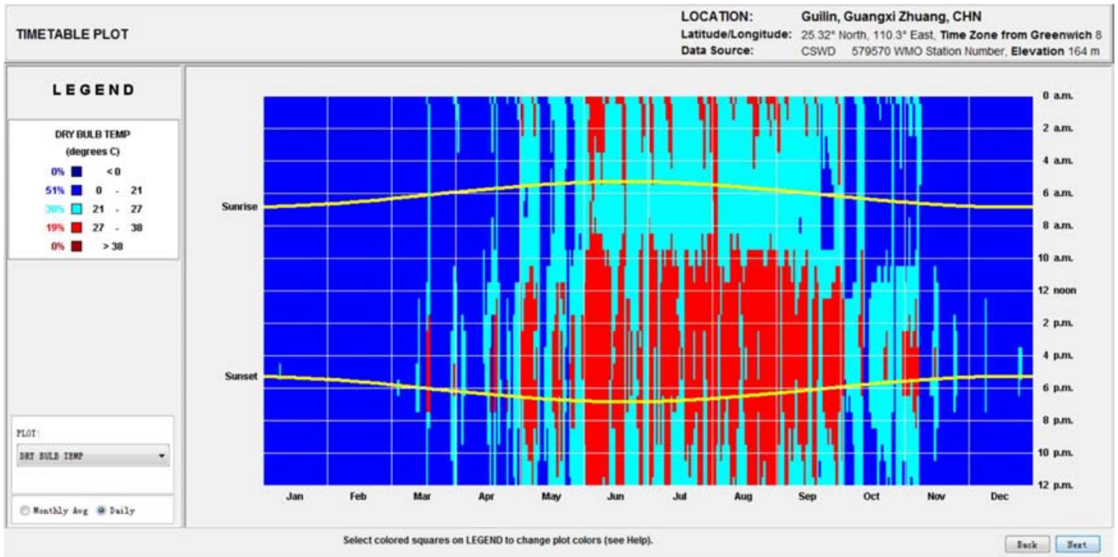

Fig.2. Timetable plot for temperature on a monthly basis

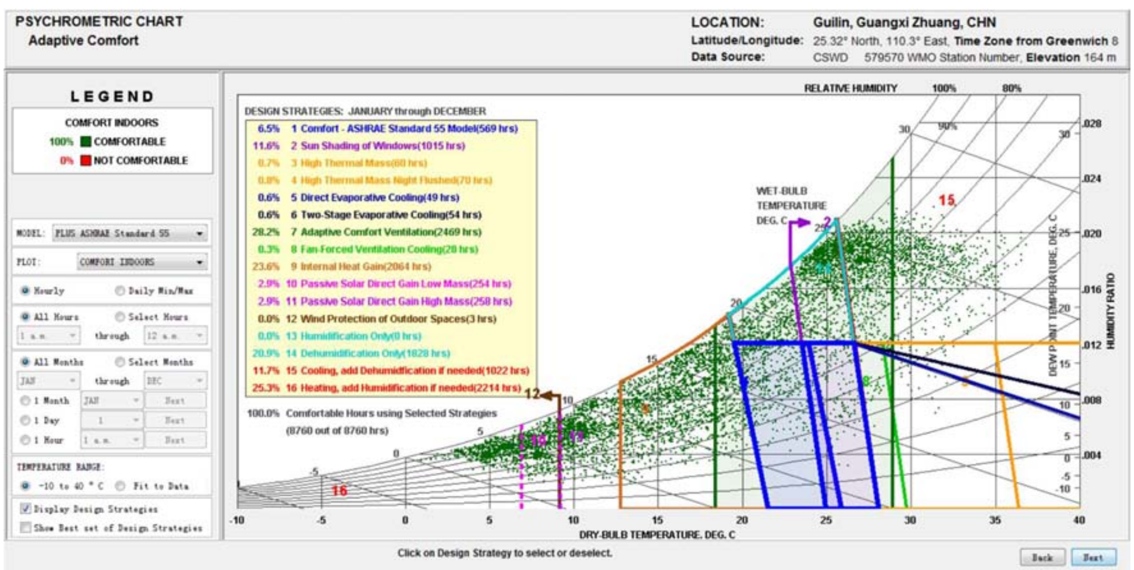

Fig.3. Psychrometric chart of Guilin climate

3.2 Schedule of hybrid operation

Figure 4 shows the hybrid operation days of the living Room. The hybrid ventilation control status is represented by three integer values: 0, 1, and 2.A zero value indicates no hybrid ventilation control. A value of one indicates that natural ventilation is allowed. A value of two denotes that the natural ventilation is not allowed, so all window/door openings are closed. A value of one for Availability Manager Hybrid Ventilation Control Mode means temperature control for either cooling or heating, which is determined internally based on thermostat set point and temperature control type. when the room temperature is above the given set point the active cooling system takes over and the windows are closed. This corresponds to the transition in the figure between the two systems, natural ventilation taking place in the morning on warm days and on cooler days it continues in to the afternoon. It must be noted that irrespective of the design option active cooling is always required. In Figure 4 it can be observed, for the whole year, the running days of individual natural ventilation is very seldom. The running days of individual heating and cooling exists in winter and summer time. Hybrid ventilation is available for most of the year.

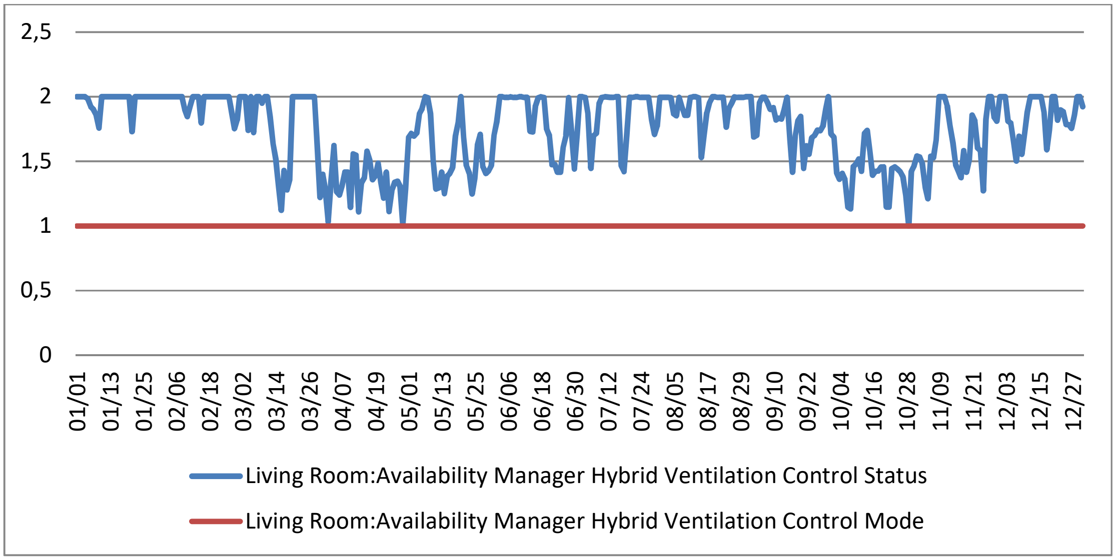

Fig.3. Operation days

3.3 Thermal comfort

Two methods were chosen to assess thermal comfort. These methods were selected because they are widely used in scientific researches and by thermal comfort professionals:
(1) Method for determining acceptable thermal conditions in occupied spaces by Fanger model (ASHRAE, 2004); (2) Method for determining acceptable thermal conditions by thermal adaptive model (ASHRAE55, 2010).
The number of Frequency days of PMV calculated by Fanger Model are shown in Fig.4. Thermal comfort days (-0.5≤PMV≤0.5) to the living room, the master room and the secondary room are 99, 101 and 105 respectively.Fig.5 shows whether the operative temperature falls into the 80% acceptability limits of the adaptive comfort in ASHRAE 55-2010. A value of 1 means within (inclusive) the limits, a value of 0 means outside the limits, and a value of -1 means not applicable. From the figure 5, we can find that there are the same days (59) of the living room, the master room and the secondary room satisfying the limits. According to the Fig 4 and Fig 5, we can conclude three rooms of the apartment do not satisfy the requirement of thermal comfort basing on current design parameters and control schedules from design standards or codes. Secondly, there are difference using the two methods to assess thermal comfort of mixed-mode spaces. Which one is the most suitable method need to be further research.

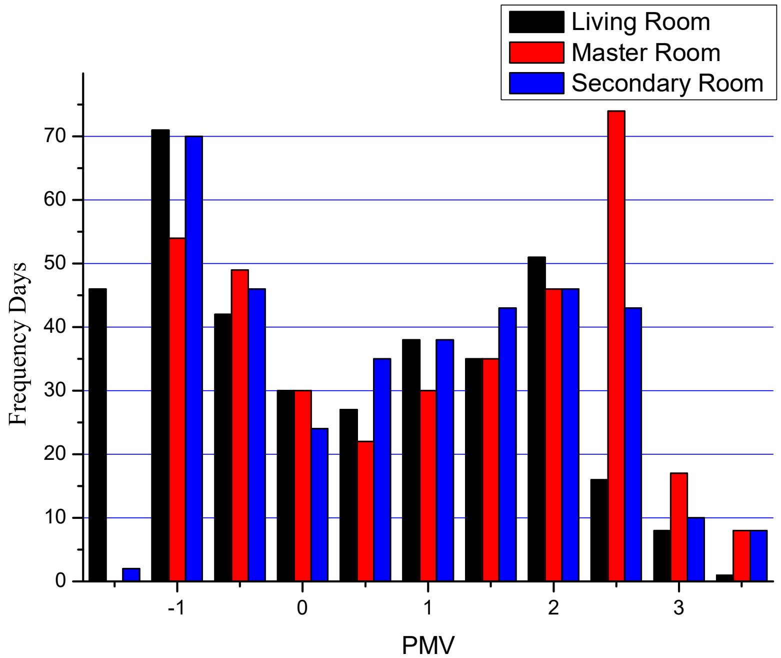

Fig.4. Frequency days of PMV

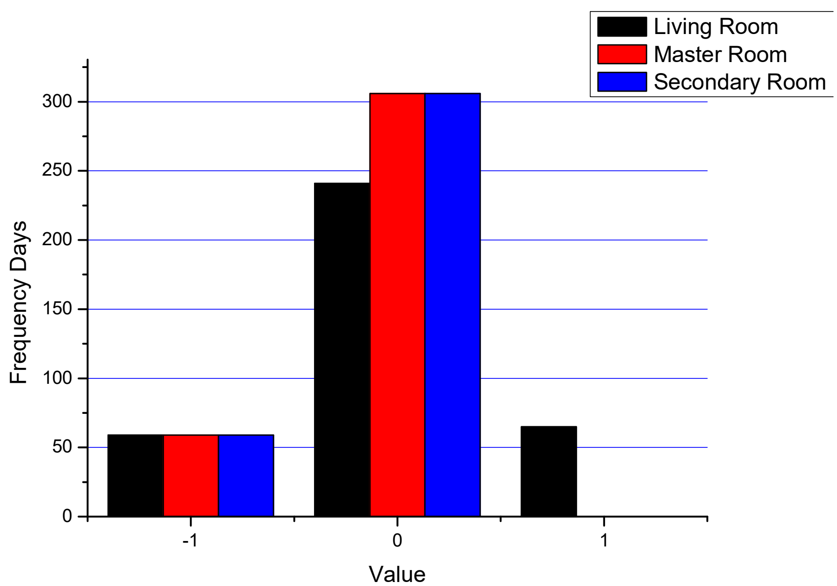

Fig.5. Frequency days of adaptive thermal comfort

Energy consumption

Fig.6 shows the plant energy consumption of main heating and cooling. From the figure, we can find the heating period is approximate from 1 April to 1 October, the cooling period from 1 January to 31 March and from 11 November to 31December.the cooling values are much less than heating value because of ventilative cooling burdening part of air conditioning load, which indicate mixed-mode cooling can reduce air conditioning load effectively. Fig.7 shows the plant energy consumption of reheat in the living room and master room, and we can find the reheat energy consumption in master room are much higher than the living room, which might attribute to different schedules of people's behaviour in the two rooms. It indicates that people's behaviour in mixed-mode spaces have an major influence to energy consumption.

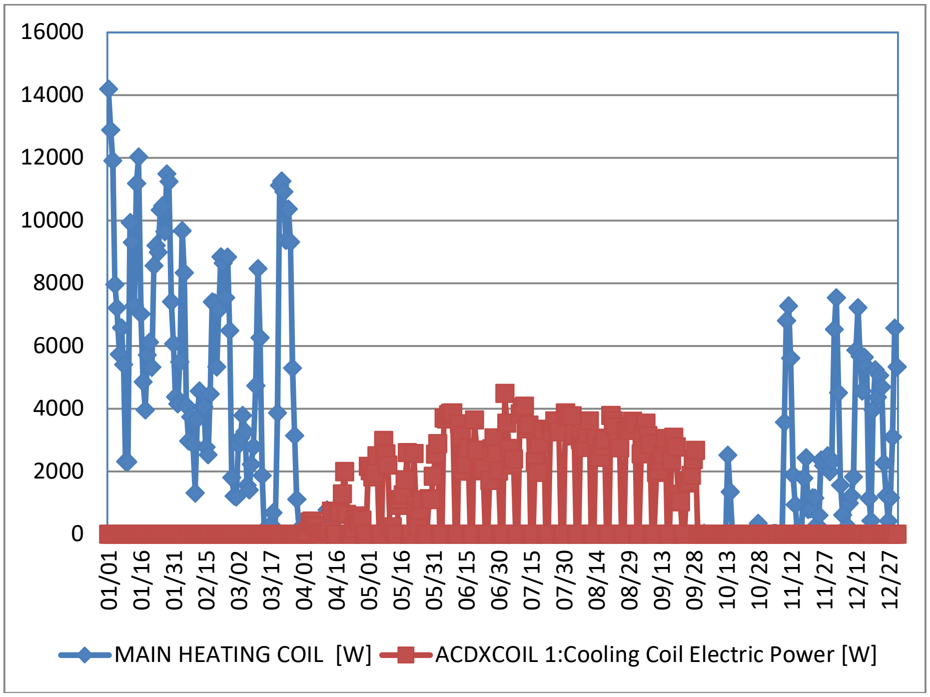

Fig.6. Plant energy consumption of main heating and cooling

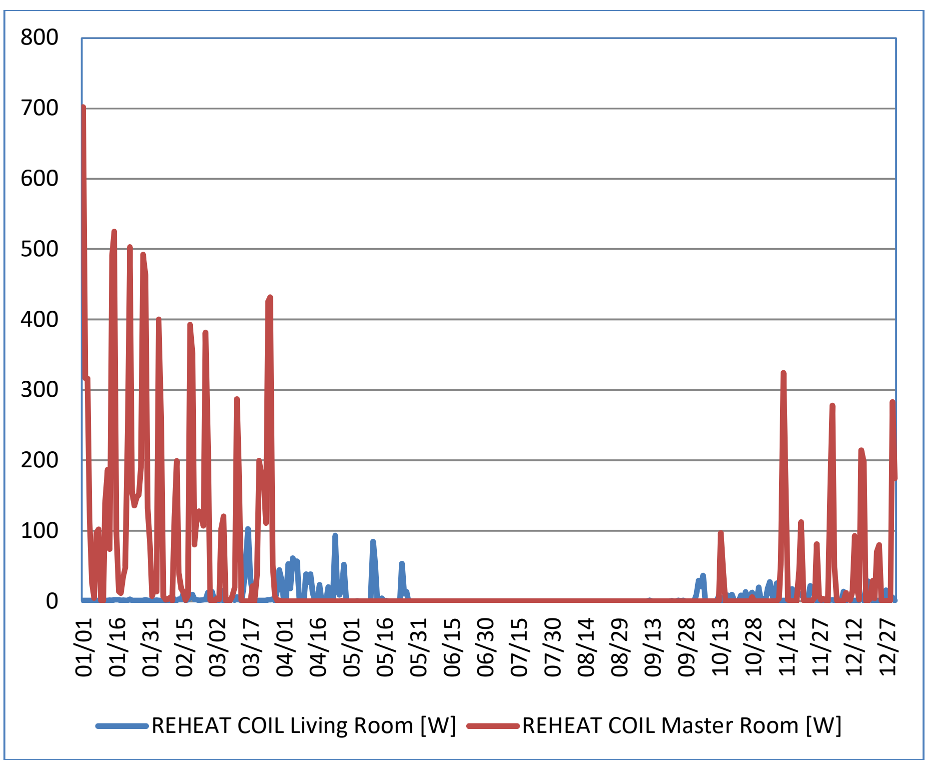

Fig.7. Plant energy consumption of reheat in living room and master room

4 CONCLUSIONS

Many studies have shown that the use of mixed-mode cooling can bring down the cooling load significantly while maintaining satisfactory in door air quality and thermal comfort. But there is little information available concerning mixed-mode cooling in China. Thus, basing on design parameters of design standard, A series of computer simulation of a typical mixed-cooling apartment in Guilin, lies south-west of China, was conducted by Eneryplus and Climate Consultant software. The following main conclusions can be drawn:

1) Natural ventilation can burden part air conditioning load but is not enough to conditioned the temperature, mechanical cooling and heating systems are needed.

2) For the whole year, the running days of individual natural ventilation, heating and cooling are very seldom. Hybrid operation is available for most of the year.

3) There are difference using Fanger model and adaptive model to assess thermal comfort in mixed-mode spaces. Which one is the most suitable methods need to further research.

4) The current design parameters of fully air-conditioning and natural ventilation buildings can not be simply used in mixed-mode cooling designs. people's behaviour in mixed-mode spaces have an major influence to energy consumption.

5 ACKNOWLEDGEMENTS

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