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Quantitative Research on Air-conditioning Virtual Energy Storage Performance of Building Air Conditioning System: A study in Shanghai

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ABSTRACT

The flexible adjustment of the air conditioning system can help smooth the load curve and absorb renewable energy. However, the quantification of building air conditioning flexibility (Air-conditioning Virtual Energy Storage， AVES) is still in its early stages. This study takes the climate and architecture of Shanghai as an example to study the changes in VES characteristics of air conditioning under different fence structures. Based on regression analysis and correlation analysis, the main factors affecting the VES of air conditioning are analyzed and quantified. This study can provide theoretical reference for the study of flexible air conditioning regulation in specific regions.

Keywords: virtual energy storage, building air conditioning system, fence structure

1. BACKGROUND

According to the "2050 Energy Zero Carbon Emissions Roadmap Report" released by the International Energy Agency in June 2021 and the "Global Energy Sector 2050 Net Zero Emissions Roadmap" released in March 2022, the core path to achieving "carbon neutrality" is the model of "Deep Electrification - Renewable Energy - Demand Side Energy Conservation". Therefore, the energy system in future urban construction is a coupling of green and low-carbon on the supply side and efficient and flexible on the demand side. Therefore, the development of flexible resources in the demand side construction field is particularly crucial [1].

Flexible resources refer to devices or objects that can increase the flexibility, resilience, and flexibility of energy supply and demand systems. Its adjustable characteristics are fully coupled with the development needs of the existing energy system, and it has achieved rapid development in recent years. With the development of building sub item measurement system and digital technology, the collaborative application of building flexibility resources and artificial intelligence has become one of the hotspots in the industry.

At the level of individual buildings, flexible resources can be divided into energy consuming equipment with regulating capabilities (such as air conditioning, lighting, and electric vehicles) and energy supply equipment (such as energy storage and cogeneration). Among them, due to the highest proportion of air conditioning systems in building energy consumption (about 30-40%) [2], so virtual energy storage (VES) technology based on flexible regulation of air conditioning systems has also become one of the current research hotspots.

2. LITERATURE REVIEW AND CONTENT

2.1 Literature review

Virtual energy storage is the process of adjusting device management strategies to transfer power demand and flatten the load curve, achieving a similar effect to energy storage devices. VES is a derivative of the concept of demand side management [3]. Virtual Energy Storage (AVES) technology based on air conditioning systems relies on the thermal inertia and thermal inertia of buildings [4]. Indoor walls, furniture, and even air can serve as cold and heat storage materials. Through the pre cooling and preheating strategy of air conditioning based on human comfort zone division, the effect of avoiding peak loads and coordinating with the consumption of renewable energy can be achieved [5].

Unlike battery energy storage and other cold and heat storage devices, AVES is influenced by various internal and external factors such as enclosure structure, heating (cooling) system, energy consumption behavior, and climate [6] (Fig 1). Therefore, accurately and quantitatively describing the energy storage characteristics of AVES and studying its influencing

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factors and dynamic changes are crucial for its rational and efficient utilization.

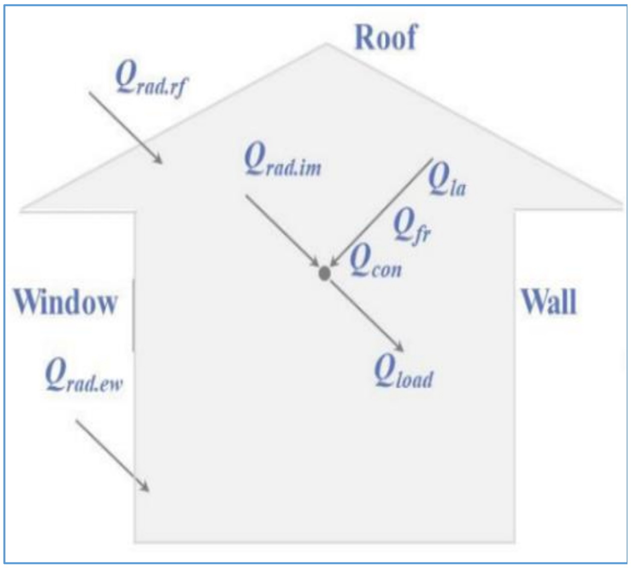

Fig.1 Schematic diagram of building energy exchange
(out (outdoor); In (indoor); RF (roof); EW (exterior wall); Im (internal air); Win (window); Rad (radiation); Con (convection); Fr (fresh air); La (indoor sensible heat); Load

AVES generally uses software simulation [7], specific scenario experimental testing, and direct or indirect characterization using control equations [8]. Arteconia et al. proposed an energy flexible building identification method that quantifies AVES through four parameters: response time, promised power, recovery time, and actual energy changes. They also studied the effects of climate, building characteristics, HVAC systems, and more. Dreams et al. [9] and Hurtado et al. [10] both used EnergyPlus for software simulation of AVES. The former analyzed the effects of different building characteristics (such as insulation, air tightness, etc.), different room temperature settings, and different heating forms (such as radiator or floor radiation heating); The latter proposes quantitative indicators such as response rate, flexible power and capacity, and charging and discharging time.

2.2 Research content

There have been some research results on the quantitative characterization of AVES, but the quantitative work still has further research value. At the same time, there are differences in the research results generated by different regions and building types. Therefore, this study takes an office building in Shanghai, China as an example. Firstly, DesignBuilder was used to model and simulated the target building. Subsequently, based on China's energy-saving standards for building design, two key variation ranges for building fence structures, namely the external wall heat transfer coefficient and the window to wall ratio, were formulated. Then, The flexibility potential of AVES is reflected by the temperature rise during different time periods after the air conditioning is turned off, which reflects the cooling capacity of the air conditioning stored indoors. Finally, through regression and correlation analysis of the results, the effects of external climate, external wall heat transfer coefficient, and window to wall ratio on the flexibility of AVES were studied.

3. LITERATURE REVIEW AND CONTENT

The target building is located in a commercial office area in Shanghai, China. The building area is approximately 5000m2. The location of Shanghai belongs to a subtropical monsoon climate, and in China's climate zones, it belongs to a hot summer and cold winter climate zone. This area has a high summer cooling demand, so the regulating potential and effect of AVES are particularly evident. This study established the target building model using the building 3D simulation software REVIT and inputted it into the energy consumption simulation software Designbuilder (Fig 2). The parameter settings of the simulation model are shown in Table 1.

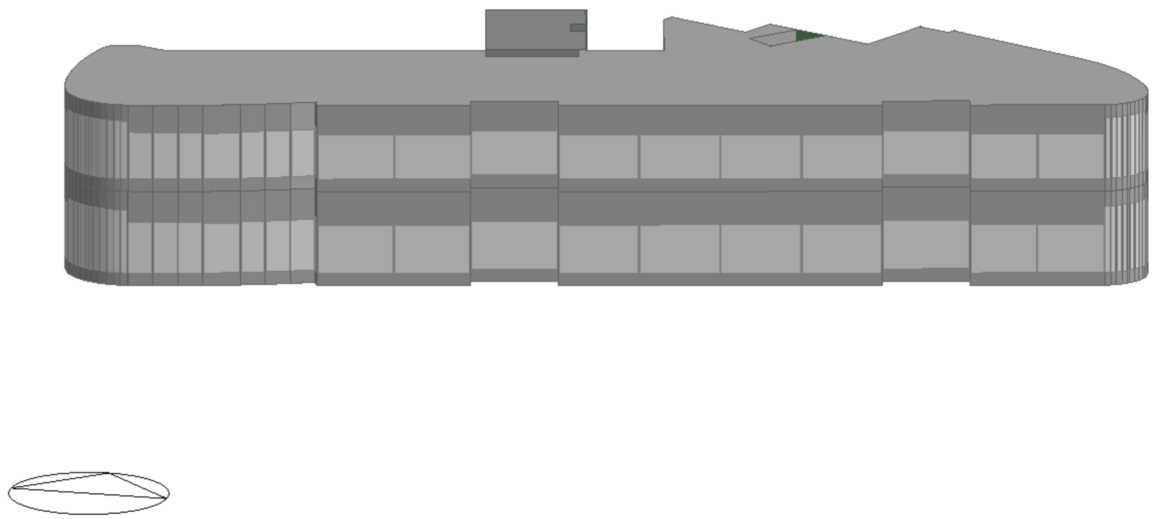

Fig. 2 Simulation Model in Designbuilder

Table 1 Simulation Model Parameter Settings

Building related settings	
External wall heat transfer coefficient	0.6 W/m2・K
Window to wall ratio	0.5
Personnel density	5 m2/person
Equipment heat dissipation	12 W/m2
Air conditioning system related settings	
Air conditioning opening temperature	28℃
Air conditioning set temperature	26℃
Average annual COP of air conditioning system	3.5
Air conditioning system form	Chiller and fan coil unit

After simulation, the annual air conditioning energy consumption of the target building is 132950kWh, and the air conditioning energy consumption per unit area is 26.4kWh/m2. This simulation result is slightly lower than the average energy consumption of public buildings (28.6 kWh/m2) announced by the government department of Shanghai in 2022. Compared with the actual test data of the target building, the error is also within 10%. Therefore, it is believed that the established simulation model is reliable.

Due to the need to study the influencing factors of AVES in this study, adjustments will be made to the set parameters. According to the three versions of China's building energy efficiency standards from 2005 to 2021 and the 2019 ultra-low energy building energy efficiency standards, the heat transfer coefficient of external walls is limited to fluctuate between 0.2 and 1. The range of window to wall ratio is 0.2-0.8. Meanwhile, due to the need for pre cooling by AVES to store the cooling capacity of the air conditioner, the set temperature for the first two hours before turning off the air conditioner was adjusted to 24 ℃ to ensure that the room was fully cooled before turning off.

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4. RESULT

4.1 Analysis of the influence of climate

For external climate factors, there are mainly dry bulb temperature, dew point temperature, solar position, radiation, wind speed, etc. Analyze the correlation between the above factors and the temperature rise after the air conditioning system is turned off, as shown in Fig 3. The dry bulb temperature shows the highest positive correlation. However, the correlation between dry bulb temperature and half hour temperature rise first increases and then decreases. The trend of changes in solar altitude angle and dry bulb temperature is relatively similar, but the overall correlation is lower. The significance level calculation of other factors shows correlation, but the correlation is relatively low. Regression of the relationship between dry bulb temperature with the highest level of significance and temperature rise is shown in Fig 4. The regression fit still shows a trend of first increasing and then decreasing, but the linear correlation is more obvious. After the air conditioning system is turned off for 2 hours, there is still a temperature rise of no more than 4 ℃ at a dry bulb temperature of 30 ℃. At this point, the indoor temperature of 28 ℃ can still ensure user comfort.

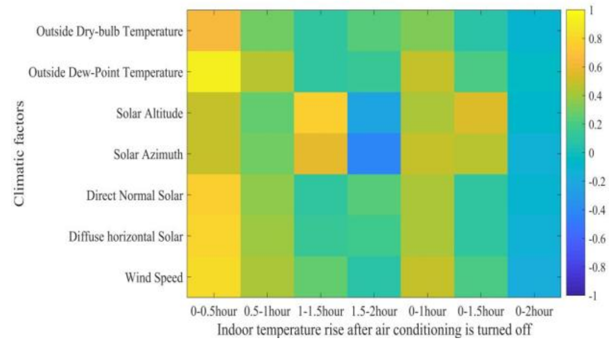
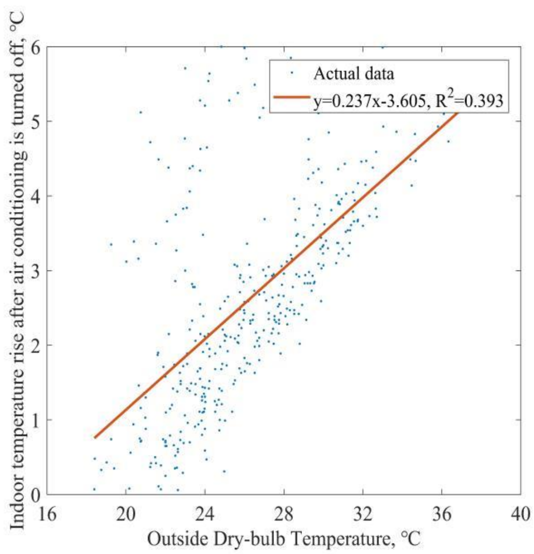
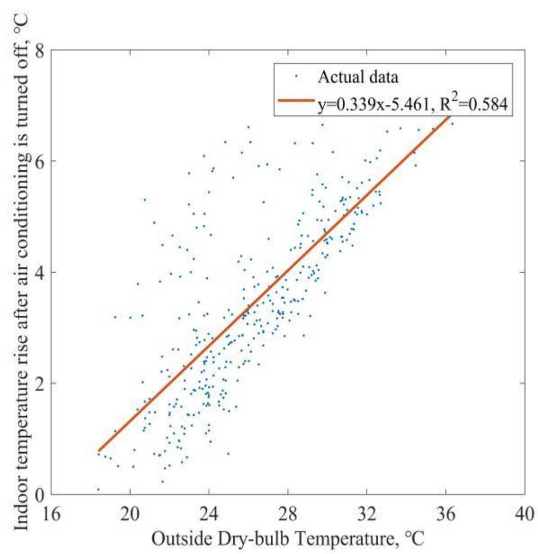


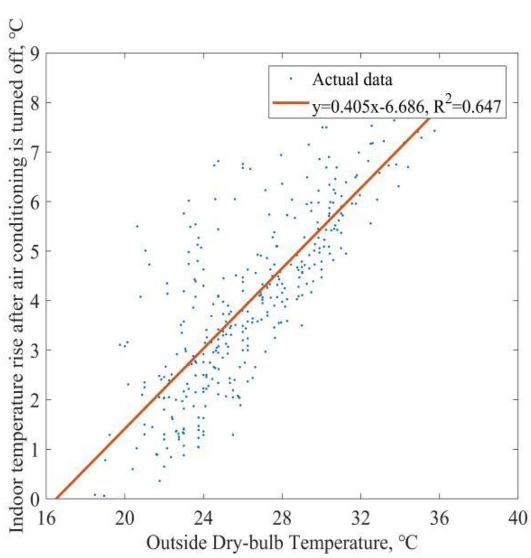
Fig.3 Correlation analysis between climate factors and AVES



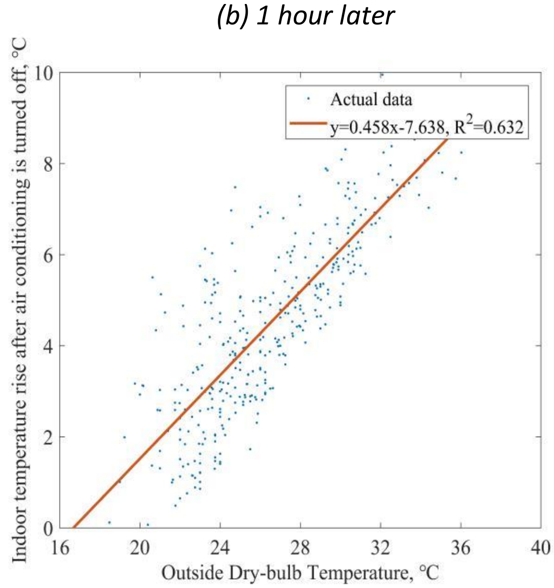
(a) 0.5 hour later



(b) 1 hour later



(c) 1.5 hours later



(d) 2 hours later

Fig.4 Regression analysis of external temperature and AVES

4.2 *Analysis of the influence of external wall heat transfer coefficient and window to wall ratio*

The heat transfer coefficient of external walls and the window to wall ratio are two important indicators in building fence structures. However, from the perspective of correlation analysis, the heat transfer coefficient of the exterior wall shows a negative correlation with the temperature rise after the air conditioning system is turned off, and the Pearson coefficient is only 0.012-0.018. The significance level is also not significant. As shown in Fig 5, the temperature rise of the air conditioning system half an hour after shutdown under different external wall heat transfer coefficients is shown. According to the typical daily analysis in Fig 6, in the simulation during the morning period, the half hour temperature rise decreases with the increase of heat transfer coefficient. The opposite situation occurs during the noon and afternoon periods. Such conflicting changes have resulted in an insignificant overall level of impact. Based on existing literature [11], from a physical perspective, the main reason for this phenomenon is that the morning irradiance and temperature are not high, and the insulation characteristics of the wall do not have a significant insulation effect on external heat. At the same time, during the morning period, it will be affected by the heat storage of the wall before the use of the air conditioner. Under the same ventilation regulation, the better the insulation performance of the wall, the faster it is unable to dissipate heat. The combination of multiple factors resulted in the results shown in Fig 5 and Fig 6.

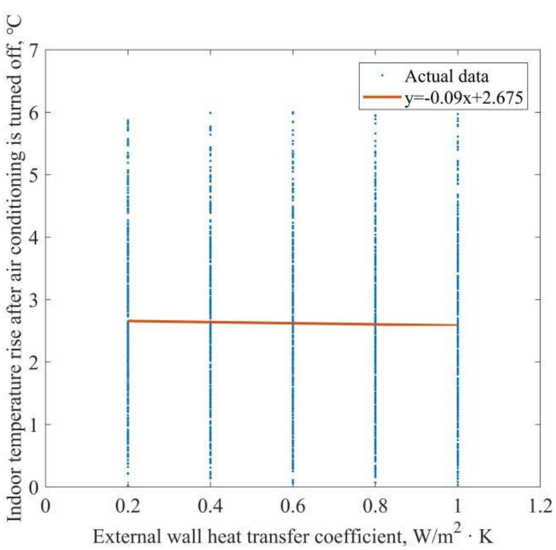


Fig. 5 Regression analysis of external wall heat transfer coefficient and AVES (0.5hour later)

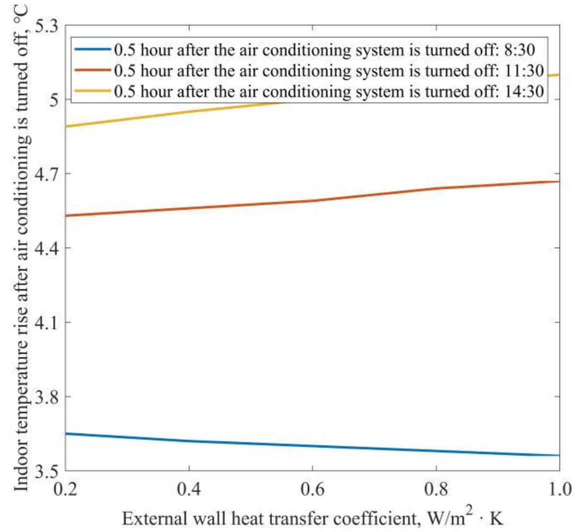


Fig. 6 Typical day analysis in August 1st

For the window to wall ratio, increasing the window to wall ratio will reduce the insulation performance of the building. At the same time, it will also cause more solar radiation heat to enter. Therefore, Fig 7 shows that the window to wall ratio is consistent with the temperature rise change after the air conditioning is turned off. Although the Pearson coefficient calculation is only 0.215-0.319, the significance level calculation is all less than 0.01. But overall, more than 30% -40% of the window wall ratio in the scenario will experience more temperature rises exceeding 4℃ in half an hour.

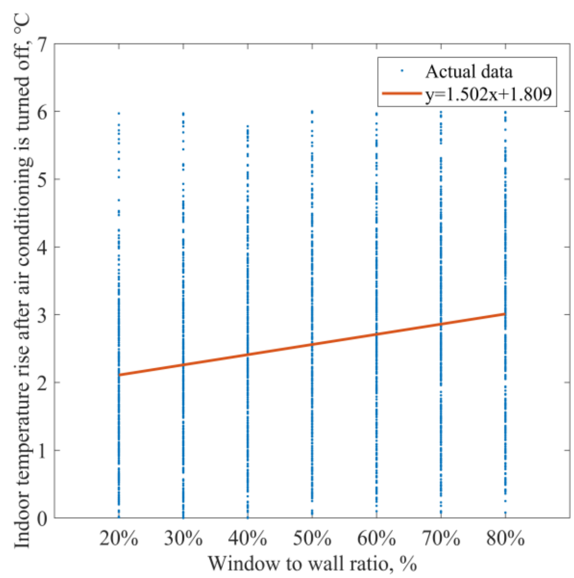


Fig. 7 Regression analysis of window to wall ratio and AVES (0.5hour later)

5. CONCLUSION

his study is based on the actual buildings in Shanghai, China, and combines the limitations of China's building energy efficiency design standards to conduct a quantitative and flexible potential study of building AVES. The significance levels of climate, external wall heat transfer coefficient, and window to wall ratio were analyzed. Based on correlation analysis and regression analysis, the following conclusions are drawn in this article:

(1) The dry bulb temperature has the greatest impact on AVES in the climate, and AVES has a large regulatory space when the dry bulb temperature is below 30 ℃ in the study area.

(2) The heat transfer coefficient of the exterior wall and AVES exhibit a temporal conflict, and in the morning, it is affected by the heat storage of the wall before the air conditioning is turned on, which cannot have a positive effect on AVES. During the noon and afternoon periods, better insulation characteristics can enhance AVES regulation space.

(3) There is a significant positive correlation between the window to wall ratio and the temperature rise after air conditioning is turned off. If AVES is carried out in buildings with high window to wall ratios, more effective shading techniques need to be considered.

The goal of this study is to provide a quantitative characterization method for the flexibility of AVES in specific climate regions. On the one hand, it provides a quantitative reference for the design and operation of the proposed urban construction energy system, and on the other hand, it also provides theoretical reference for the quantification of AVES in other climate regions.

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