Energy Proceedings
Vol 41, 2024
ISSN 2004-2965

Application Potential Analysis of a New Dynamic Building Envelope in Public Buildings

Hengxin Zhao[1, 2] , Shuangdui Wu[1, 2] ,Yifan Wu[1, 2] , Hongli Sun[2, 3] , Borong Lin[1, 2 *]

1 Department of Building Science, Tsinghua University, Beijing 100084, China

2 Key Laboratory of Eco Planning & Green Building, Ministry of Education, Tsinghua University

3 College of Architecture and Environment, Sichuan University, Chengdu, 610065, China
(*Corresponding Author: linbr@mail.tsinghua.edu.cn)

ABSTRACT

With the process of global urbanization, public buildings have been developed on a large scale, and energy conservation and emission reduction in this field are crucial to environmental protection. Passive energy saving through optimizing public building envelope does not need to consume other energy, which has great application potential. Therefore, this study innovatively uses a new type of thermal diode and combines it with the building envelope to form a dynamic building envelope that can passively remove heat and heat insulation, which can reduce the energy consumption of public buildings and promote cross-innovation of different disciplines. Numerical simulation was used to investigate the potential of the dynamic building envelope in public buildings. The results showed that the cooling energy saving potential of the building envelope was between 12.30% and 21.59% in different climate zones, and it had certain climate adaptability. At the same time, the energy saving potential increases with the increase of heat source in the building, reaching a maximum of 27.20%. Compared with the traditional building envelope, this new dynamic building envelope has stronger adjustment ability and better passive energy saving effect, which provides a certain reference for the development of energy saving in the building field.

Keywords: dynamic building envelope, building energy saving, passive thermal diode, simulation optimization

NONMENCLATURE

Abbreviations	
CDD	Cooling Degree Day
EMS	Energy Management System
HDD	Heating Degree Day

1. INTRODUCTION

With the process of global urbanization, the building area has increased rapidly, and the energy consumption has also developed rapidly [1]. In recent years, public buildings have been developed on a large scale, and total energy consumption has been increasing at an annual rate of 10% [2]. Moreover, public buildings generally have high energy consumption and low energy efficiency [3]. Therefore, energy conservation and emission reduction in the field of public buildings are crucial to environmental protection and the solution of energy crisis.

Since the building envelope is the main component of the building, it plays a key role in determining the comfort, natural lighting, ventilation level, and energy consumption of building heating and cooling [4]. Therefore, enhancing the performance of the building envelope can improve the energy saving potential of public buildings to a certain extent.

For the improvement of building envelope performance, the performance-adjustable envelope has been more developed in recent years [5] [6]. Compared with the traditional envelope, the adjustable building envelope can make corresponding performance adjustments with the changes of indoor and outdoor environment, and reduce the building energy consumption. Therefore, it is possible to reduce the energy consumption of public buildings by trying to use the new performance-adjustable building envelope. In recent years, the jumping-droplet phenomenon and the formation of jumping-droplet thermal diodes have been studied [7][8]. The working modes are divided into two types: forward and reverse mode, in which the forward mode has a high heat transfer coefficient and the reverse mode has a low heat transfer coefficient. With its

This is a paper for 15th International Conference on Applied Energy (ICAE2023), Dec. 3-7, 2023, Doha, Qatar.

excellent unidirectional heat transfer capacity and unique flat plate structure, it can be combined with the envelope of public buildings to form an envelope with adjustable performance.

As shown in Figure 1, the jumping-droplet thermal diode is initially considered to be used on the roof of a public building. During the summer daytime, the temperature of the outer surface of the roof is higher than the temperature of the inner surface. At this time, the jumping-droplet thermal diode is in mode (a) and acts as heat insulation. At night, for public buildings such as office buildings and shopping malls, the air conditioning is generally turned off, coupled with the delay of heating during the day, at this time the indoor temperature will be higher than the outdoor temperature, the jumping droplet diode is in mode (b), and the internal phase transition heat transfer can achieve passive cooling at night, reducing the energy consumption of air conditioning startup in public buildings the next day, to achieve the role of energy saving.

Based on the above assumptions, as shown in the research route in Figure 2, this study uses Designbuilder and Energyplus simulation tools to model and simulate the public buildings combined with the jumping-droplet thermal diodes. Through the simulation of different variables, the energy-saving proportion of public buildings in different climate zones is calculated. Therefore, the feasibility and potential improvement space of combining jumping-droplet thermal diode with building envelope as adjustable envelope are verified and discussed. This paper aims to provide some technical references for heat transfer switchable building envelope and energy saving of public buildings.

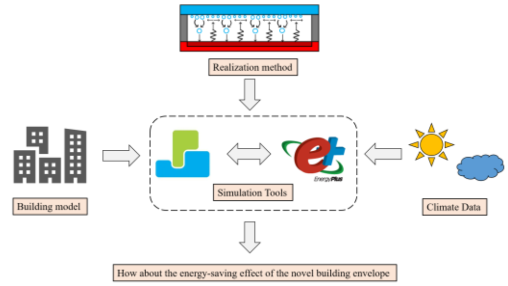

Fig. 2 Research methods and routes

2. METHODS

In order to verify the operational energy-saving effect of the jumping-droplet thermal diode combined with the building envelope, the energy-saving effect and applicability of the novel building envelope will be clarified by simulation, taking different climate zones in China as examples. Since the combination of jumping-droplet diode and building is firstly selected on the roof, considering that public buildings such as exhibition halls and convention centers are mostly single-story large roof structures, which can effectively use the energy-saving advantages of the envelope, the building model is modelled in DesignBuilder. At the same time, the operation logic of this performance-adjustable envelope is controlled in the Energy Management System (EMS) module of Energyplus. The building model is shown in Figure 3.

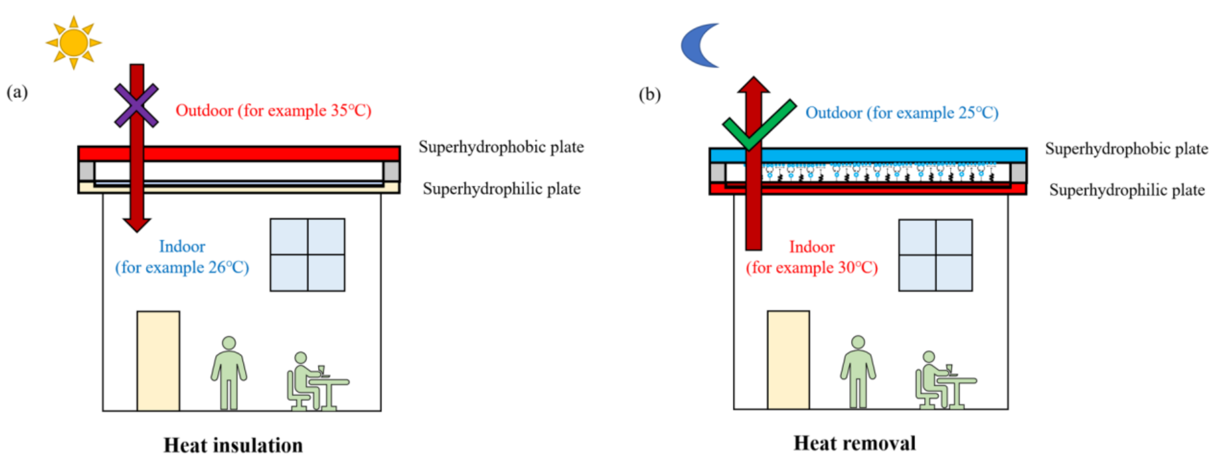

Fig. 1 The working principle of the novel building envelope

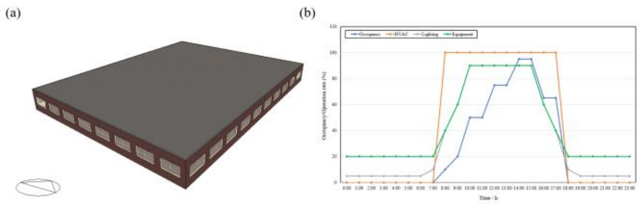

Fig. 3 Prototypical building model and schedules

For public buildings, the parameters are set according to the Design Standard for Energy Efficiency of Public Buildings [9]. The building and other related information is summarized in Table 1.

Table 1. Building feature information

Model features	Unit	Value
Basic information		
Building length	m	54
Building width	m	42
Story height	m	5
Story quantity		1
Envelope information		
Window-wall ratio		0.3
Roof U-Factor	W/(m^{2}K)	0.5
External wall U-Factor	W/(m^{2}K)	0.8
Glazing U-Factor	W/(m^{2}K)	2
Solar heat gain coefficient		0.3
HVAC information		
Winter indoor air temperature	℃	20
Summer indoor air temperature	℃	26
Chiller COP		3
Gas boiler efficiency		90%
Internal heat gain information		
Occupancy density	p/m^2	0.2
Equipment power density	W/m^2	20

3. RESULTS AND DISCUSSION

3.1 Annual simulation results for hot summer and warm winter region

Considering that the building envelope incorporating jumping-droplet thermal diode is more favorable for passive heat removal, Haikou, a city in the hot summer and warm winter region, is firstly selected for the analysis of cooling energy saving potential throughout the year. The simulation results are obtained as shown in Fig. 4.

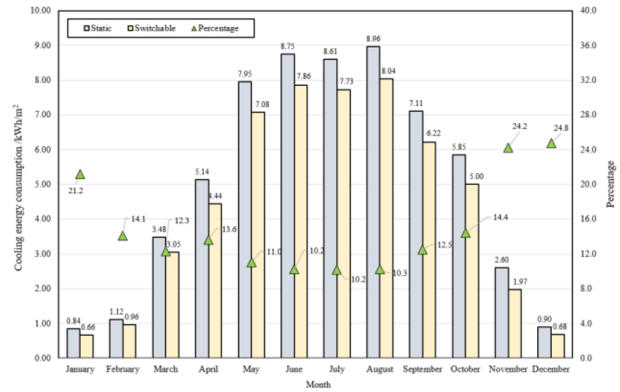

Fig. 4 Annual simulation results for hot summer and warm winter regions

From the simulation results of Haikou for the whole year in Fig. 4, we can see that the proportion of energy saving in cooling for the whole year is 12.43%, which has a certain energy saving effect. Among them, the proportion of energy saving in winter is larger than that in summer, mainly due to the small absolute value of cooling energy consumption in winter, so a relatively small absolute value will cause a large change in the relative value.

Furthermore, the indoor temperatures of the dynamic building envelope and the indoor temperatures of the conventional envelope in Haikou in four months, 1, 4, 7 and 10, were selected for comparison. The results are shown in Fig. 5, from which it can be seen that the green line represented by the dynamic envelope is lower than the red line of the static envelope at higher indoor temperatures. Where the heat dissipation temperature difference is between 3-5°C, and this heat dissipation temperature difference will gradually increase with the increase of the internal heat source.

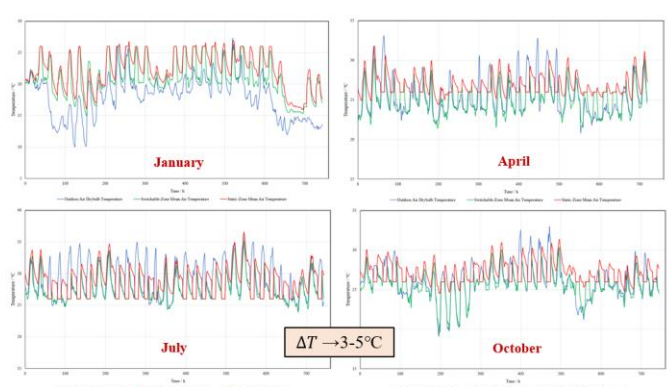

Fig. 5 Comparison of temperatures in typical months

3.2 Simulation results of energy consumption in different climate zones

In order to further investigate the energy saving effect of this dynamic public building in different climate zones, seven Chinese cities in seven climate zones were selected for simulation with CDD10 from high to low according to ASHRAE standards. The climate information of different cities is shown in Table 2.

Table 2. Characteristics of Chinese climate zones

ASHRAE climate zone	City	CDD 10 (℃-days/year)
1A	Haikou	5234
2A	Guangzhou	4468
3A	Chongqing	3208
3C	Kunming	5234
4A	Beijing	2274
6A	Shenyang	1763
7	Harbin	1385

From the figure 6, it can be seen that for each of the seven climate zones, the jumping-droplet thermal diode envelope has a certain energy saving potential in terms of cooling energy consumption, which reaches 12.30-21.59%, and it also shows that this type of envelope has a certain degree of climatic adaptability when it is applied to public buildings. In addition to this, the large absolute value of heating energy consumption due to the general coldness of the 4-7 climate zone results in a relatively low percentage of total energy savings. For the total energy saving effect, it is the largest in the Haikou area, reaching 12.30 %, which also indicates that the building envelope is more suitable for areas where cooling is dominant.

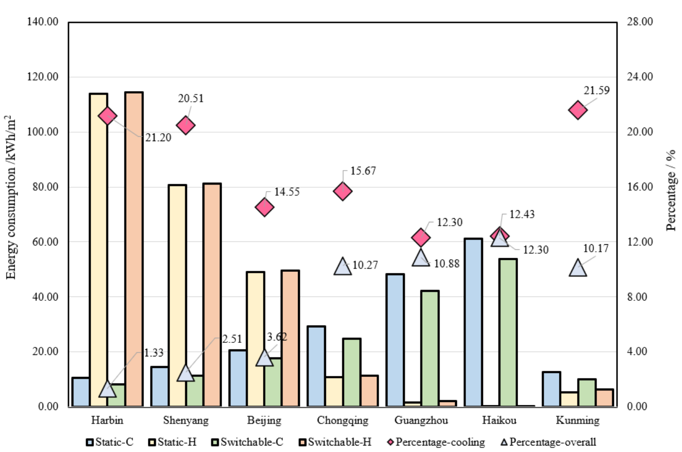

Fig. 6 Comparison of energy savings in different climate zones

3.3 The influence of different internal heat source intensity of public buildings

From the simulation results in the previous two sections, it can be seen that the main working interval of the public building incorporating the jumping-droplet thermal diode is at night, which is more conducive to the reduction of cooling energy consumption, and that the different heat source of the building will have an effect on the energy saving effect. Therefore, in the following figure 7, six scenarios are set up with the intensity of the building's internal heat at night from 0-50% to study the effect of different internal heat effects on the energy saving of this building.

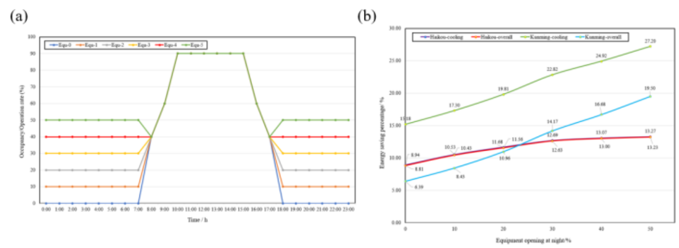

Fig. 7 (a) Settings of different internal heat intensities (b) Simulation results for two climate zones

As can be seen from the figure 7, for the cities of Kunming and Haikou, the overall percentage of energy savings increases for both cities as the equipment opening increases at night. The increase in energy saving percentage is about 13% for Kunming and about 4.2% for Haikou. The percentage of energy savings is larger in Kunming than in Haikou due to the small absolute value of the overall energy consumption in Kunming. The resultant trend also illustrates the role of the nightly heat intensity on the energy savings of public buildings using this dynamic building envelope. Therefore, the building envelope incorporating jumping-droplet thermal diode is also more favorable for the application of buildings with greater internal heat intensity.

4. CONCLUSION

This paper proposes a novel building envelope incorporating jumping-droplet thermal diodes. Compared with conventional building envelope, the passive energy saving potential and dynamic adjustment ability of the building envelope are stronger. The paper analyses the potential of this novel building envelope for application in public buildings by means of simulation. The energy saving ratio of cooling energy consumption in different climate zones ranges from 12.30 % to 21.59 %, which has a certain climate adaptability. And this energy saving potential increases with the increase of the intensity of the internal heat source in the public building up to 27.20%. The combination is simpler and more effective than the conventional dynamic envelope. This study provides some references for the energy saving of public buildings and the development of building envelopes.

ACKNOWLEDGEMENT

The study was supported by the National Natural Science Foundation of China (Grant No.52130803), the National Science Fund for Distinguished Young Scholars (Grant No. 51825802), the New Cornerstone Science Foundation through the XPLORER PRIZE, the China Postdoctoral Science Foundation (2023M732479), Sichuan Province Innovative Talent Funding Project for Postdoctoral Fellows (BX202218) and the Fundamental Research Funds for the Central Universities (YJ2021126).

REFERENCE

[1] Ren C, Zhu H-C, Wang J, Feng Z, Chen G, Haghighat F et al. Intelligent operation, maintenance, and control system for public building: Towards infection risk mitigation and energy efficiency. Sustainable Cities and Society 2023;93:104533. https://doi.org/10.1016/j.scs.2023.104533.

[2] Gan L, Ren H, Cai W, Wu K, Liu Y, Liu Y. Allocation of carbon emission quotas for China's provincial public buildings based on principles of equity and efficiency. Building and Environment 2022;216(5):108994. https://doi.org/10.1016/j.buildenv.2022.108994.

[3] Zhao J, Xin Y, Tong D. Energy consumption quota of public buildings based on statistical analysis. Energy Policy 2012;43(8):362–70. https://doi.org/10.1016/j.enpol.2012.01.015. https://doi.org/10.1016/j.enbuild.2019.07.004.

[4] Zhang S, Sun P, Sun EP. Research on energy saving of small public building envelope system. Energy Reports 2022;8(2013):559–65. https://doi.org/10.1016/j.egyr.2022.03.146.

[5] Dabbagh M, Krarti M. Evaluation of the performance for a dynamic insulation system suitable for switchable building envelope. Energy and Buildings 2020;222(1):110025. https://doi.org/10.1016/j.enbuild.2020.110025.

[6] Pflug T, Bueno B, Siroux M, Kuhn TE. Potential analysis of a new removable insulation system. Energy and Buildings 2017;154(6):391–403. https://doi.org/10.1016/j.enbuild.2017.08.033.

[7] Boreyko, Jonathan & Zhao, Yuejun & Chen, Chuan-Hua. Planar jumping-drop thermal diodes. Applied Physics Letters 2011. 99. 234105.

[8] Boreyko JB, Chen C-H. Vapor chambers with jumping-drop liquid return from superhydrophobic condensers. International Journal of Heat and Mass Transfer 2013;61:409–18. https://doi.org/10.1016/j.ijheatmasstransfer.2013.01.077.

[9] MoHURD (Ministry of Housing and Urban-Rural Development of the People’s Republic of China), The People’s Republic of China National Standard GB50189-2015, Design Standard for Energy Efficiency of Public Buildings, Beijing, 2015.