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Article

Energy-Saving and Ecological Renovation of Existing Urban Buildings in Severe Cold Areas a Case Study

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ABSTRACT: High-rise buildings in cold regions have a requirement of ecological improvement due to the continuous response to climate change throughout the year. The piece evaluates the wind environment, light environment, thermal environment, and energy consumption environment using Phoenics, Ecotect, and DesignBuilder tools, utilizing a high-rise residential building in an intensely cold place as an example. With the goal to repair the buildings, green energy-saving measures are applied from the perspectives of form, structure, system, and equipment strategy. The energy-saving rate and carbon dioxide emission reduction rate of the renovated buildings were predicted. Results reveal that: in the building performance diagnostic, the wind speed clearly rises at the building's corner, particularly on the outdoor level and the top floor; meanwhile, the inside lighting is insufficient, and there is a glare hazard adjacent to the window. The performance of the target building has unquestionably increased with the repair of 12 measures, including bay windows, exterior walls, and solar energy. The area of strong winds in winter and tranquil winds in summer greatly decreased in terms of wind environment. In the light environment, indoor lighting is more uniform, the range of (Universal Design index) UDI100-2000 increased from 9.2% to 32.7%, UDI2000 which may cause glare decreased by 28.4%. Energy savings and pollution reduction rates are as high as 19.8% and 38.8% respectively, due to the installation of solar photovoltaic panels. Based on all the measures, the overall energy saving rate of the target building is 63.8%, and the CO_2 emission reduction rate is 90.3%.

KEYWORDS: Severe cold area; existing buildings; physical environment; renovation; energy-saving; emission reduction

1. Introduction

Due to the enormous effect on the climate, the link between architecture and energy use has become a key concern in recent years. The need for structures and infrastructure rises along with the expansion of metropolitan areas and the world's population, which results in increasing energy usage. A sizeable portion of the greenhouse gas emissions are caused by the building construction and operation. The situation can be improved by taking measures in the aspects such as building design, materials, heating and cooling systems, and energy-efficient technology[1, 2]. Building energy consumption is an important part of global energy consumption, accounting for 32%, and building heating energy consumption accounts for 32%-34% of the total energy consumption [3-5]. By 2020, China's total building area is 83.302 billion square meters, of which residential buildings are 60.356 billion square meters, including urban residential buildings are

27.842 billion square meters, and non-residential buildings are 22.946 billion square meters. [6,7]The energy consumption generated by construction activities accounts for 26.7% of the total energy consumption of the whole society [8-10]. Many existing buildings have issues such as high energy consumption, erratic carbon emission, poor environmental function, and other issues because early architectural design and construction standards were constrained by economic factors and construction technology [11–13]. As a result, many buildings still stand today with these issues. Therefore, it is crucial to carefully research eco-friendly renovations of existing structures in extremely cold regions [14, 15].

Earlier research regarding the rehabilitation of structures was conducted. The selected green building rating system standard was adopted by Suman et al. [16] , then a new framework to determine the best renovation strategy of existing office buildings based on cost-benefit analysis was developed, which provides early decision support for the sustainable renovation of office buildings. Kalamees et al. [17] constructed energy efficiency model and economic feasibility analysis model for residential renovation, which provided a reference for Estonian buildings to develop energy saving measures and renovation schemes Inspired by which, the building renovation paradigm adopted in this study considers economic feasibility. Simple and economical ways of retrofitting old buildings were favoured. Assimakopoulos et al. [18] developed the simulation model of the building-factory system and examined the effects of the St. George's Palace industrial refurbishment on energy usage and the environment. In recent ten years, the research on building renewal has developed rapidly. Xu et al. [19] developed a new hybrid energy system of solar air collector + air source heat pump + energy storage, which is used for building energy saving of ultra-low energy consumption in severe cold areas. The feasibility and performance of the hybrid energy system are studied in Hailar region. Fu et al. [20] investigated the key technology from the external design, enclosure structure and energy supply of energy-saving buildings by taking the Qiyi department store as an example. In comparison, this piece provides more measures and metrics used to save energy and reduce emissions, though does not provide an in-depth discussion around these technologies. According to each stage of the super high-rise building life cycle, Fang et al. [21] established the environment of super high-rise buildings impact evaluation system after thoroughly analyzing the impact of super high-rise buildings on the environment during the construction and operation management phases. Li et al. [22] designed the three-dimensional dimensionless energy saving index parameters of atrium office buildings in severe cold areas, which solved the contradiction between flexibility and universality of atrium geometry that are not affected. Aiming at the new type of energy-saving building with concrete sandwich straw block houses, Jiang et al. [23] measured its cold consumption index and heating power consumption index through experiments, and conducts experimental research on its thermal insulation performance and moisture performance. In addition, they also studied the energy-saving effect of external thermal insulation wall of prefabricated residence in hot summer and cold winter areas [24]. In the research of this paper, it was found that the measure of "installing light-blocking mirrors" also has a significant effect on energy saving and emission reduction, which is a supplement to the previous research. Xu et al. [25] established the optimization model of existing building renovation with the outdoor average universal thermal climate index (UTCI) as the performance index to evaluate urban microclimate. At present, the evaluation indexes of energy consumption are mostly included in the green building evaluation standards and energy-saving design specifications.

With the passage of time, existing buildings will face the problems of structural deterioration, functional obsolescence and high energy consumption. In this paper, a high-rise residential building in a severe cold region was selected and its wind, light, thermal and energy consumption environments were simulated using Phoenics, Ecotect and Design Builder software. The basic performance of the building was diagnosed and analyzed. In order to achieve the reduction of energy consumption and CO2 emissions, form strategies (outdoor wind environment and indoor lighting), structural strategies (façade and roof), system strategies (heating, water supply and power supply, etc.), and equipment strategies (light fixtures, awnings, wind deflectors, etc.) have been adopted in the targeted weak areas. A prediction of the energy saving and emission reduction rate of the retrofitted building was made.

The common perception is that saving energy and improving energy utilization is always the key to energy efficiency in building systems. At the same time, renewable energy is the leading direction of energy consumption development.

The characteristic that can be identified is that most of the current green building evaluation standards and energy efficiency design codes include evaluation indicators for energy consumption, and these focus on assessment from the design perspective, while less assessment is made for existing buildings and buildings in the use phase. This study attempts to make a degree of addition in this area by proposing energy efficient and emission reduction retrofit solutions for a given sample of in-use buildings.

Another point is that in existing research on buildings and the environment, monitoring and diagnostics are mainly focused on the control aspects, and diagnostics are generally carried out using neural networks or fuzzy control and computer simulation to achieve diagnostic functions, with less research on failure diagnosis and runtime optimization. The failure diagnosis methods used in this study follow a certain logical structure system, and the architectural optimization approach forms an effective matching combination, which supplements the available data and information for the above two aspects. Compared with most of the existing studies that focus on the theoretical level, this study is closer to practice, and can provide a reusable and imitable evaluation system and retrofit methodology for the optimization of the ecological environment of buildings for more high-rise building retrofits in similar environments. The limitation is that more samples and cases are needed to confirm the applicability of the results of this study.

2. MATERIALS AND METHODS

Chennengxi Tree Garden Community was built in 2002, located in No.117 Haxi Street, Nangang District, Harbin City, Heilongjiang Province. Winters in the area are lengthy and bitterly cold. The average temperature in January is about 19 degrees below zero, and the heating time is up to 6 months [26-28]. The residential group consists of six point-type high-rise residential buildings, one small high-rise slab residential building and supporting public buildings. The reconstructed building No.4 is a point-type high-rise residential building located on the windward side of summer, with butterfly-shaped plane and four households in one staircase. The interior is divided into two permeable households and two sunny households, both of which are three rooms and one hall. The interior is small, large depth and one side lighting, which is not conducive to natural lighting and ventilation, as shown in Figure 1. The most prominent feature of the target building is that there are bay windows in four directions, which increases the building surface area and heat loss.

For the renovation of the targeted building, the methods are as follows: (1) Primary wind, light, and thermal energy consumption environments are included in the basic performance diagnosis of the target building. Phoenics software is used to simulate the wind field at 1.5 m elevation of the target building throughout several seasons as part of the wind environment diagnostic. Outdoor wind speed, wind pressure differential, indoor air age, and surface wind speed are the primary evaluating factors. With

DF(Daylight Factor), DA(Daylight Area), UDI and DAmax as evaluation criteria, Ecotect software was selected to diagnose the overall light environment in the building. Through the Design Builder software, the operation energy consumption and operation carbon emissions of the target building are calculated after the parameters such as shape coefficient, external wall structure and window-wall ratio are input]. (2) Aiming at the high energy consumption area of the building, the renovation design is carried out from four aspects: strategy, structure strategy, system strategy and equipment strategy. This paper proposes 12 measures, such as removing bay windows, local overhead, installing wind deflectors and solar energy utilization, dredging outdoor wind environment, optimizing indoor thermal environment, improving indoor light environment, and introducing sustainable energy utilization, to comprehensively optimize existing building performance. (3) The rate of energy savings and CO2 emission reduction that can be achieved after a building renovation is predicted by comparing the physical environment changes before and after the renovation, combined with the single target sensitivity analysis of various measures.

3. RESULTS AND DISCUSSION

As a result of the increased wind pressure on the windward side of the structure, unfavorable circumstances including top gradient wind, bottom corner wind, and narrow pipe flow will develop. In order to demonstrate the wind environment field, light environment field, and thermal energy consumption field one by one [29,30], it is essential to diagnose the performance of the target building.

Figure 1. Photos of existing buildings.

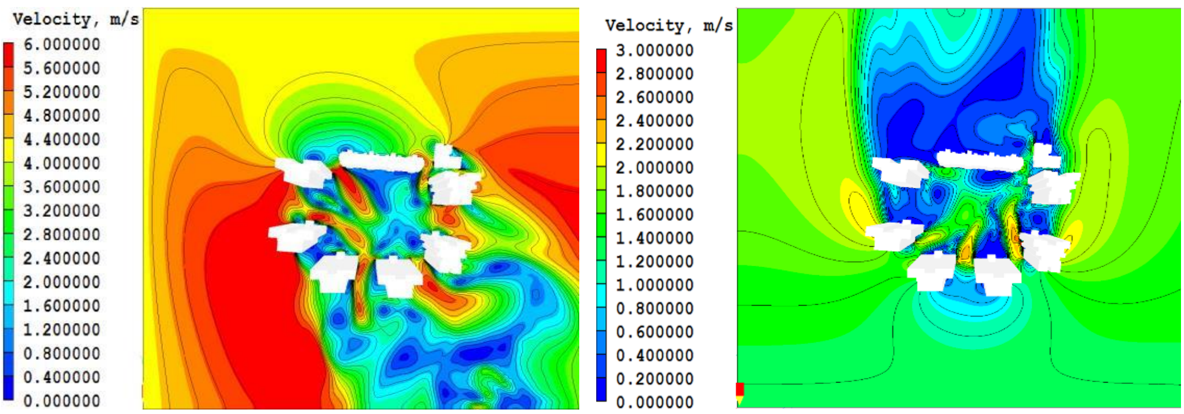

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Figure 2 (a). Wind velocity of the measuring building area in summer and winter

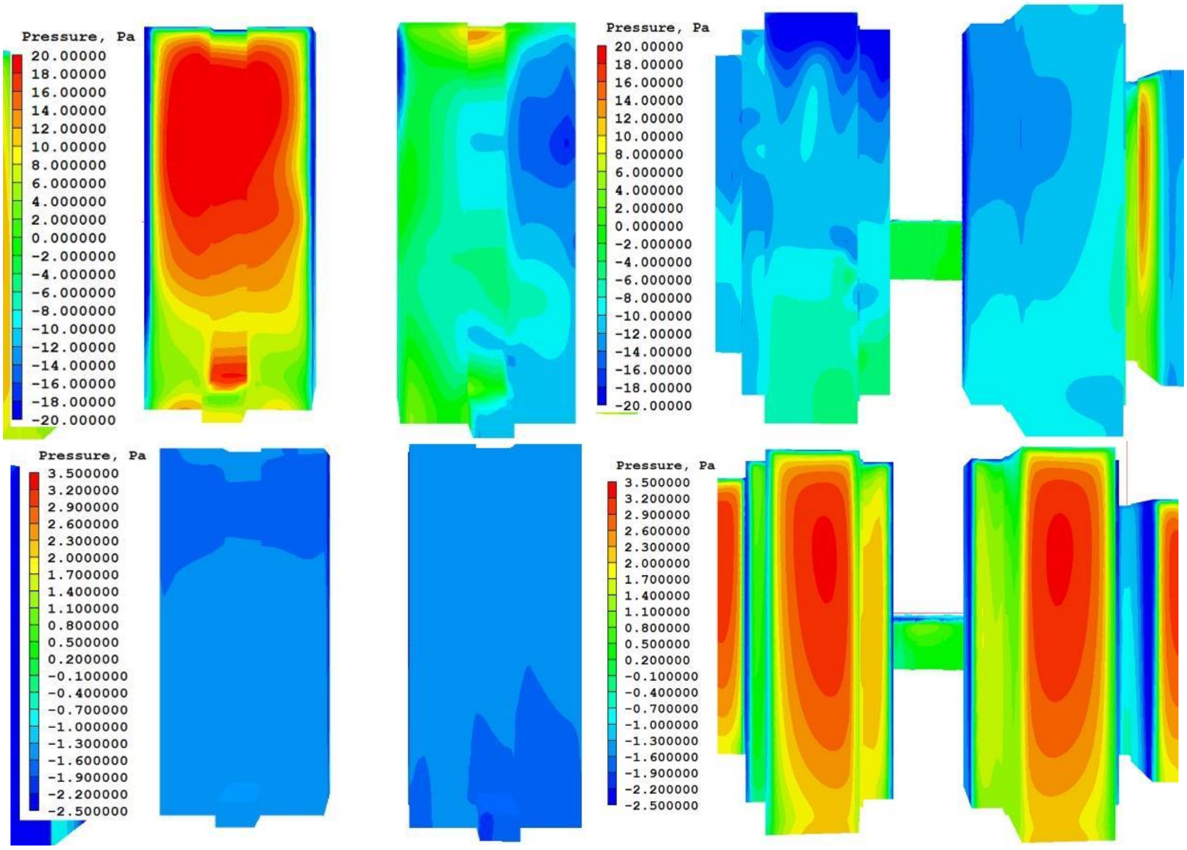

Figure 2 (b). Wind pressure of the measuring building area in summer and winter.

Wind environment. Chennengxi Tree Garden Community is designed as an enclosed layout of high-rise group. In winter, the wind speed is about 2.6-6.0 m/s near the 1.5 m elevation of the ground, especially in the active site surrounded by buildings. The wind speed at many places is more than 5.5 m/s and the wind amplification factor is 1.5 (6/4). Although the building is not at the windward position, the wind pressure difference between windward side and leeward side in winter is still large, about 10-26 Pa. In summer, the target building is located on the windward side, the outdoor wind speed is 1.5-2.3 m/s at 1.5 m elevation, the area of static wind area is small, and the wind pressure difference on the building surface is 2.6-4.8 Pa, which is conducive to the formation of natural ventilation inside the building. At the height of 16th floor in summer, the air age of indoor main space is 0-320 s, and the ventilation condition is good, which is conducive to health. However, the problem of surface wind speed is serious in winter and the local wind speed at the upper windward side is 4.8-6.0 m/s, which leads to excessive inlet wind speed in appropriate ventilation period in winter, as combined information reflected from Figure 2.

Light environment. The point-type amazed encased building of Chennengxi Tree Cultivate Community is more likely to meet the lighting conditions beneath the same building dividing. Hence, the daylight time of all floors of the target building on the cold day is more prominent than 2 hours. The indoor light environment recreation comes about are appeared in Figure 3. In which, DF de-notes that the lighting coefficient of 53% of the measuring focuses is more prominent than 2%, and the normal brightening is

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4.14%. DA indicates all measuring focuses within the unit plane is 0-94%. 51% of all the measuring focuses reached DAmax over 5%. Within the indoor light environment recreation, it can be seen that the inside lighting is insufficient, and the glare close the window is apparent. In this manner, the room confronting south is chosen for point by point examination. The chosen room measure is 3500 × 5600mm, and inlet window estimate is 1800mm × 2100mm × 600mm. The recreation comes about are appeared in Figure 4. The lighting coefficient of 28% of the measuring focuses is greater than 2%, and the normal brightening is 2.09%. All measuring focuses within the unit plane is 65-93%. UDI100 is 24%, UDI100-2000 is 9%, and UDI>2000 is 66%. The narrows window plays the part of self-shading, amplifying the engendering way of indoor light, coming about in haziness within the profound window, and glare near the window is apparent, comfortable light environment dispersion zone is contract.

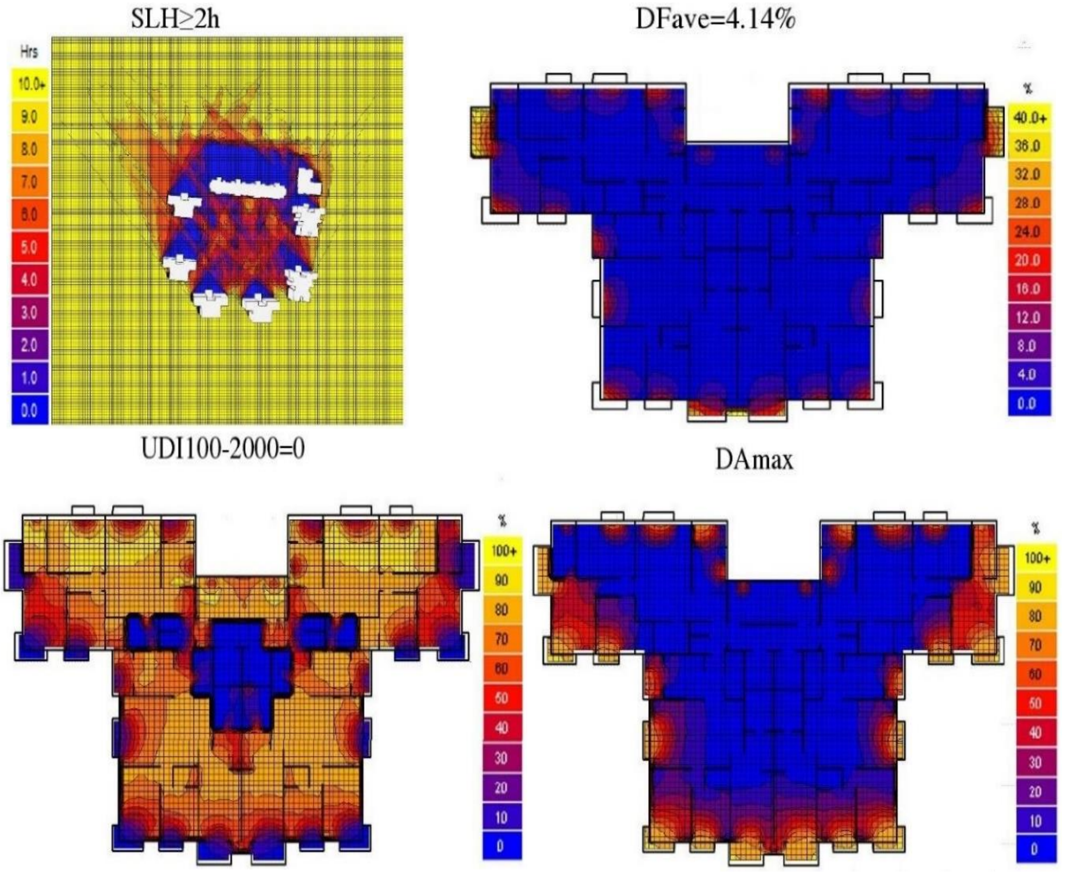

Figure 3. Diagnostic chart of indoor light environment.

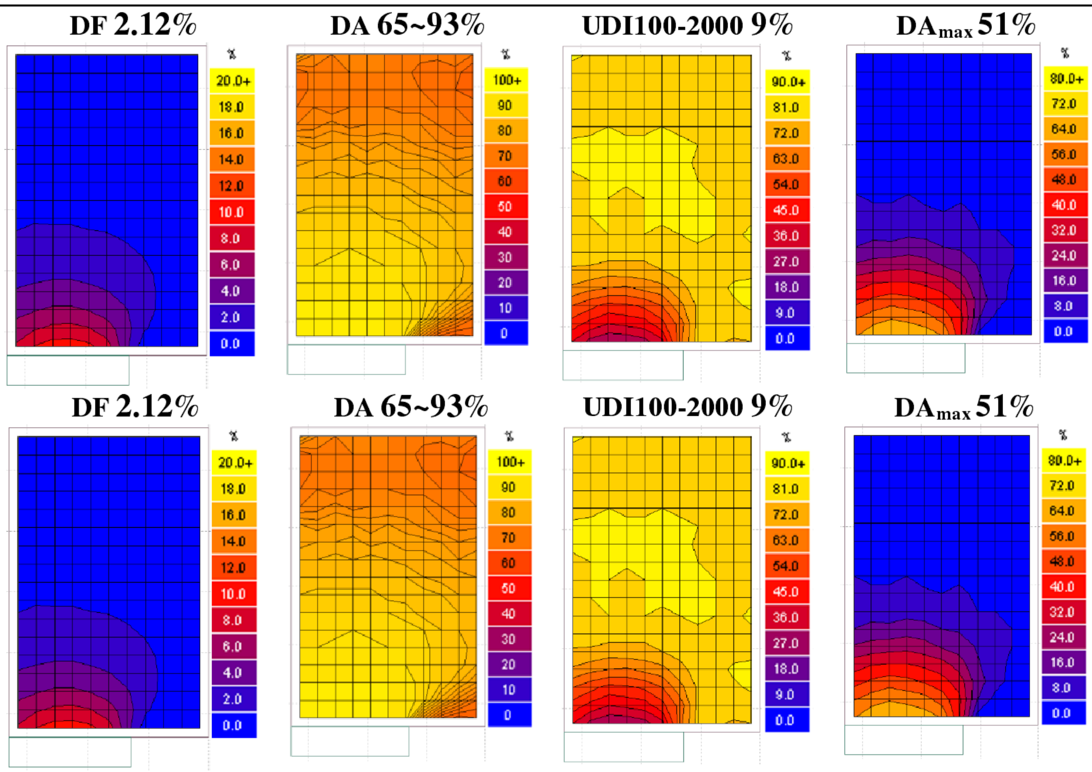

Figure 4. Diagnostic chart of light environment in south bedroom.

Table 1. Diagnostic table of thermal performance.

Building parameters	Actual building	Standard building
Figure coefficient	0.27	0.26
Exterior wall structure	Reinforced concrete, 200mm; EPS insulation board, 50mm; U-value = 0.642W/m²·k	Reinforced concrete, 200mm; EPSinsulation board, 50mm; U-value = 0.642W/m²·k
Roof structure	Reinforced concrete roof, 120mm; XPSinsulation board, 50mm; U-value = 0.588W/m²·k	Reinforced concrete roof, 120mm; XPSinsulation board, 130mm; U-value = 0.247W/m²·k
Hall structure	Double glass curtain(6/l3mm); U-value = 2.665W/m²·k	Double glass curtain(6/l3mm); U-value = 1.786W/m²·k
Outer window	Double glass curtain(6/13mm); U-value = 2.665W/m²·k	Double glass curtain(6/13mm); U-value = 1.786W/m²·k
Window wall ratio	S 0.35	0.35(0.3-0.7)
	N 0.26	0.26(<0.4)
	E 0.2	0.20(<0.45)
	W 0.2	0.20(<0.45)
Operating energy consumption	85.26 kWh/m²·a	70.76 kWh/m²·a
Operating carbon emissions	46.31 kg/m³·a	42.59 kg/m³·a

Thermal and energy consumption environment. Although the building has received alterations to some extent, the No.4 building of Chennengxi Tree Garden Community has been built more than 20 years originally. The design parameters such as shape coefficient, external wall structure and window-wall ratio were not significantly different from those of the standard building. The operation energy consumption and carbon

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emissions of the target building were 85.26 kWh/m^2·a and 46.31 kg/m^3·a, respectively, which were only 17% and 8.1% higher than those of the standard building, as shown in Table 1. Therefore, the space for reducing energy consumption and CO_2 emissions from the structural aspect is relatively small, and it is expected that the green renovation design of the target building will be mainly improved by system strategy.

Renovation design and prediction feedback. Chennengxi Tree Garden Community is located in Harbin City, the regional climate is long and cold in winter, heating time is long. Therefore, in the target building energy consumption distribution, heating accounts for the highest proportion of energy consumption, which is 61.4%, followed by domestic hot water 20.8%, lighting 13.2% and refrigeration 4.6%. In the renovation measures, the problem of improving the bay window is first considered. The existence of bay window greatly increases the exterior area of the building, resulting in the shape coefficient exceeding the limit. At the same time, the local overhead method is used to dredge the outdoor wind environment in the design. Then the door hall is added with the sunshade board and the wind deflector to optimize the indoor thermal environment and wind environment. In addition, the performance of the existing building has been comprehensively optimized by strengthening the insulation performance of the enclosure structure, replacing the outer window and other structural strategies and systematic measures such as sub-metering and sustainable energy utilization.

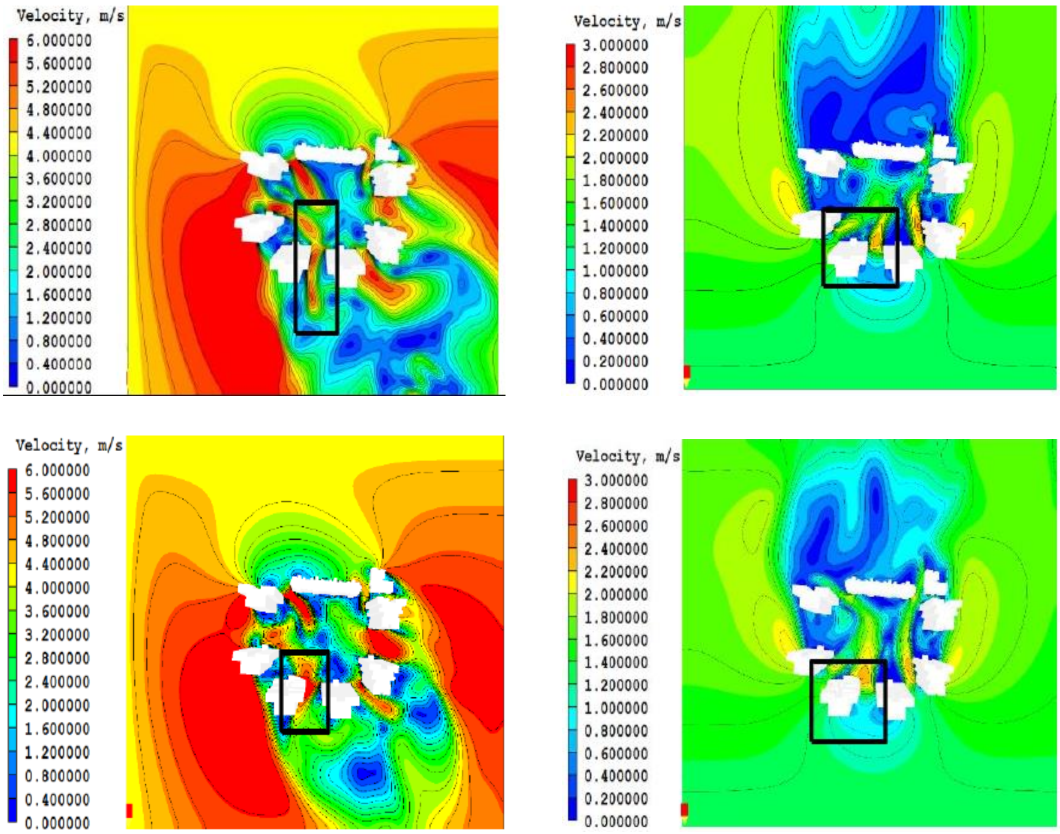

Figure 5. Comparison of outdoor wind environment before and after renovation.

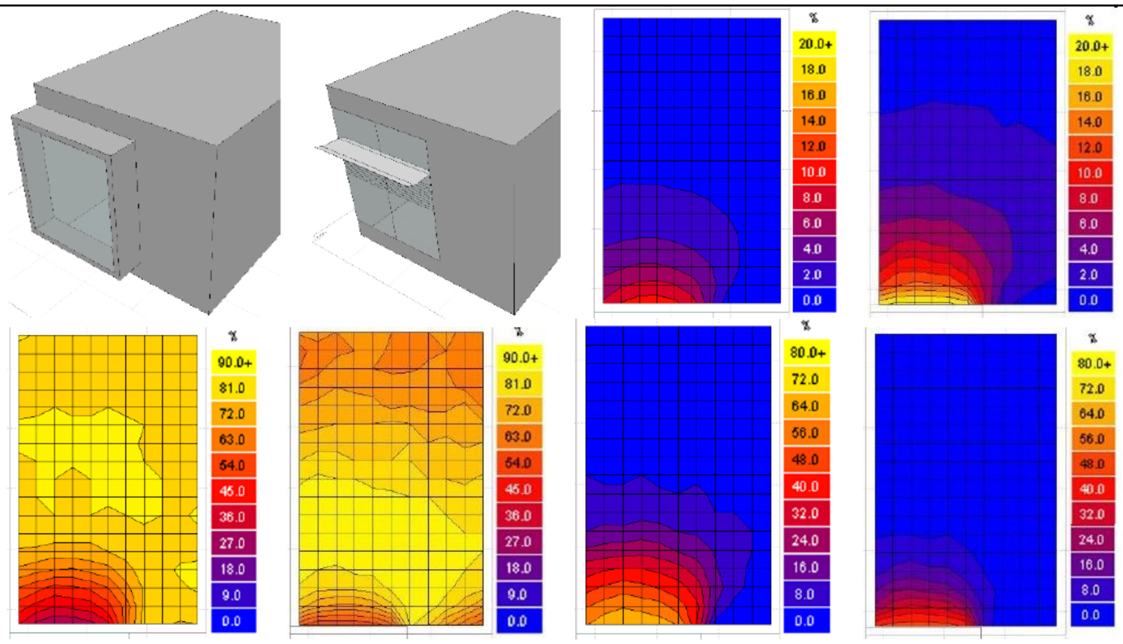

Figure 6. Comparison of light environment optimization of shading reflector.

Formal strategy: The main goal of the form strategy is to enhance the efficiency of indoor lighting and optimize the impact of external wind conditions. In accordance with the design's shear walls, the eastern room of the target building has been removed and transformed into a semi-open space for activities, as part of the overall strategy. Significantly, this alteration has been carried out while keeping the same number of households and without compromising the strength of load-bearing walls. Before and after the retrofit, a thorough examination of the building's wind conditions has been carried out using Phoenix software. Figure 5 visually depicts the distribution of the resulting wind field. It is important to acknowledge that every building in the group has the ability to impact the microenvironment of the entire area. Modifications have been made to the overhead space to improve outdoor comfort. These modifications not only reduce the impact of winter winds, especially in regions with wind speeds of 5. 6 m/s or higher, but also enhance the calmness of the wind conditions in areas designated for summer activities, where wind speeds are below 0. 6 m/s

To alleviate worries regarding the lack of transparency in the modeling process, the authors have provided additional details on particular elements of the retrofit strategy. One example is the detailed explanation of how the addition of PV panels, solar collectors, and other components affects energy usage and the subsequent emission of greenhouse gases. Extensive discussions have taken place to ensure transparency and reproducibility regarding the assumptions, simplifications, and considerations made by the model, including those related to factors such as the electricity mix employed.

The positioning of wind deflectors on the northern side of the building has been carefully implemented to mitigate the higher wind speeds encountered on the upper portions of the building's exterior. Figure 6 illustrates five separate wind guide elements designed to lower surface wind velocities in the main functional zones on each level. Through the use of simulations, specific concerns have been detected, as indicated by the highlighted portion in Figure 7. In the fifth simulated situation, precautions have been implemented to limit the region exposed to high wind velocities to 3. 2 m/s A cleverly devised strategy for optimization is specifically directed towards important areas such as bathrooms and cooking spaces, leading to a highly effective approach.

The authors have used Ecotect software to simulate how the modified design affects indoor illumination in order to improve the lighting environment. The distribution of indoor lighting has been enhanced by incorporating adjustable shading and reflective elements in place of the original bay windows. The shading structure is designed to effectively reduce the impact of direct sunlight in the summer months. Significant enhancements involve a significant boost of 23. 5% in the UDI100-2000 range, a notable decrease of 28. 4% in UDI2000 (which has the capability to produce glare), and a considerable reduction of 47. 5% in the DAmax area (where illuminance exceeds 5%). In addition, the use of vertical greening on the mountainsides facing east and west has a double function, providing insulation in the summer and helping to decrease the need for cooling energy. To address issues with glare and enhance indoor lighting, shading elements and reflectors have been installed on the southern side of the building, as shown in Figure 8. In an effort to reduce wind speeds on the upper parts of the building, wind deflectors and extra windshields have been installed on the northern side.

Effect on Carbon Emissions: A comprehensive analysis of the modification strategy's effect on carbon emissions has yielded noteworthy reductions. In a precise estimation, the implementation of shade reflectors is anticipated to yield a potential decrease of 7% in emissions, whereas the elimination of bay windows could potentially lead to a reduction of 4%.

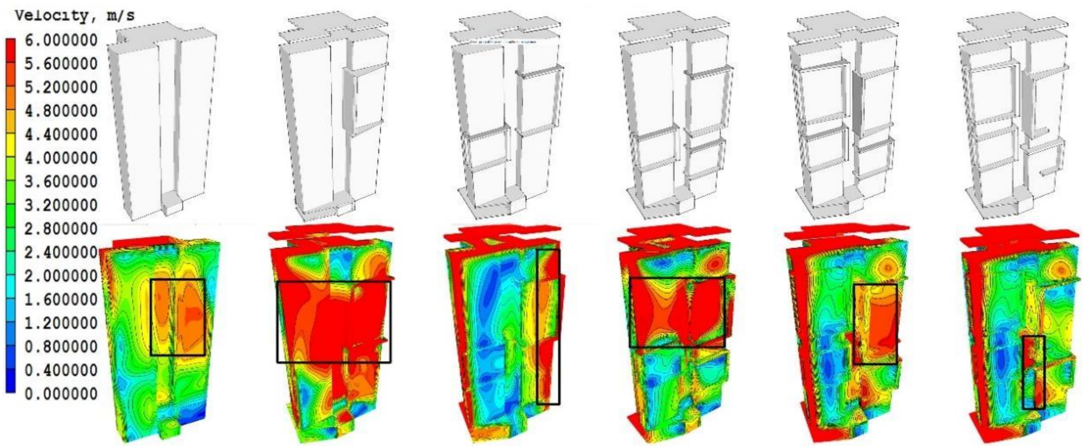

Figure 7. Design of wind deflector.

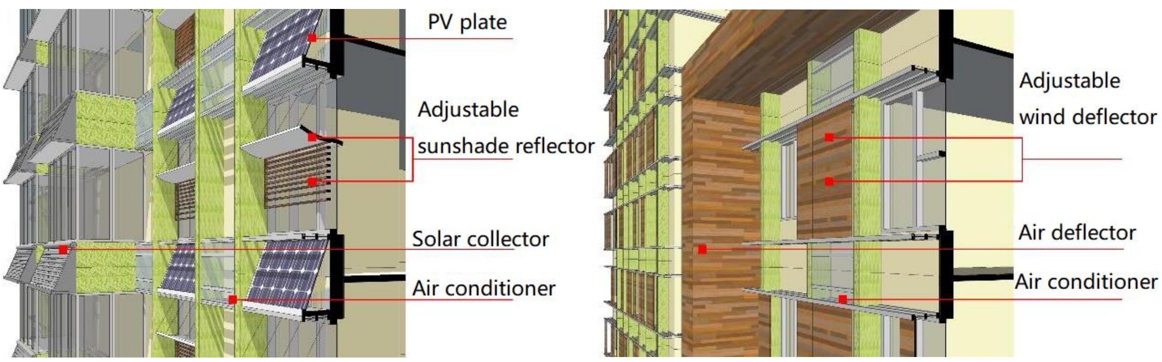

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Figure 8. Renovation strategy of target building.

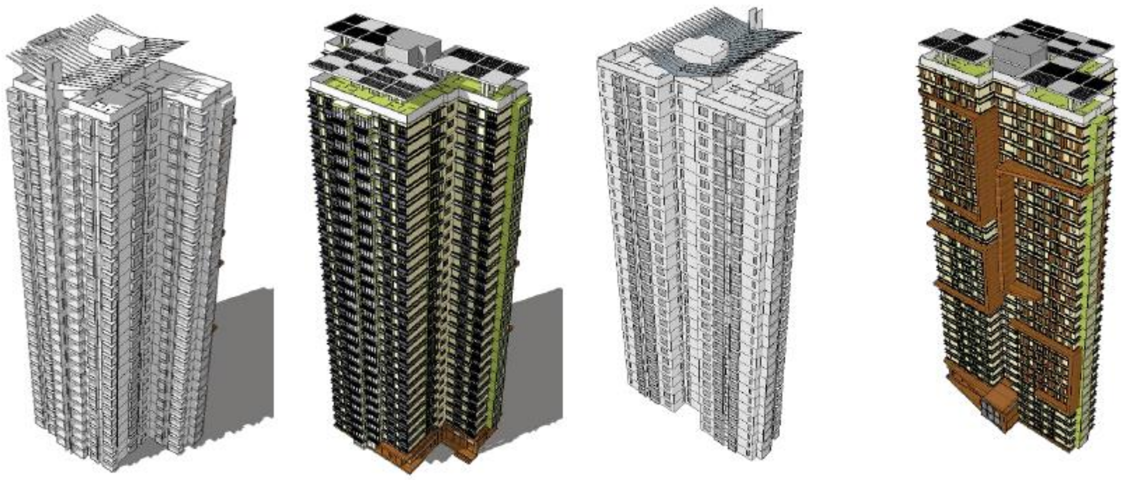

Figure 9. Comparison of architectural modeling before and after renovation.

Table 2. Energy-saving and CO_2 emission reduction performance of different individual strategies.

Strategy	Measures	Energy consumption	Energy- saving rate(%)	CO_2 ($kg/m^2 \cdot yr$)	Emission reduction rate(%)
Actual building		85.26		46	
Formal	Remove the bay window	77.2	9.5	44.15	4
	Local overhead	85.15	0.1	46.09	0.2
	Additional lobby	85.14	0.1	45.97	0.1
	Sunshade reflector	83.87	1.6	42.78	7.0
Construction	External wall insulation	81.38	4.5	45.34	1.4
	Roof insulation	84.72	0.5	45.91	0.2
	Outer window	81.23	4.7	45.05	2.1
System	Heating	79.26	7.8	44.81	2.6
	Solar collector	77	9.7	37.27	19.5
	Solar photovoltaic	68.38	19.8	28.15	38.8
Device	Energy-saving lighting	80.71	5.3	39.36	14.4
Comprehensive		31.57	63.8	2.62	90.3

The *Table 2*, displays the energy-saving and CO2 emission reduction performance attributed to several strategies. Each strategy has been meticulously outlined in terms of their respective associated measures, energy consumption values, energy-saving rates, and CO2 emission reduction rates. The strategy labeled as "Comprehensive" exhibits notable advancements, achieving a noteworthy 63. 8% decline in energy consumption and a 2. 62% reduction in CO2 emissions.

Construction, system strategy and equipment strategy. The target building has EPS and XPS insulation layers on the outer walls and roof, which have high thermal insulation performance but still fall short of the present specification's criteria. Therefore, in the renovation design, the external wall thermal insulation is thickened by 20 mm, and the roof is thickened by 90 mm, so that the heat transfer coefficient of the external wall is reduced from 0.64 W/m^2·K to 0.43 W/m^2·K, and the heat transfer coefficient of the roof is reduced to 0.25 W/m^2·K. The common double-layer glass (2.665 W/m^2·K) is replaced by double-layer LOE glass (1.786 W/m^2·K). The structure is identical to that of a typical building. The findings of the energy consumption simulation demonstrate that the structural approach contributes less to the reduction of emissions than the formal method. The emission reductions of external wall reconstruction, roof reconstruction and window replacement are 1.8%, 0.3% and 2.6% respectively. The system improvement strategy has achieved remarkable results, and the comparison of architectural modeling before and after the renovation is shown in Figure 9. Among them, solar photovoltaic panels can effectively save energy by 20.4% and by emission reduction 39.2%. Using the balcony to install panel 304.65 m^2, the solar collector can supply all the domestic hot water energy consumption, which can effectively save energy 9.8% and emission reduction 19.0%. In addition, in terms of equipment strategy, the emission reduction of LED lamp replacement is 145.2%.

Energy saving and emission reduction. The Design Builder software is used to simulate the energy consumption of 12 measures in the renovation, the standard formulae for each indicator are embedded in the software. The enhancement in energy saving and emission reduction performance, as well as the carbon emission and cost increment, are used to determine the sensitivity of energy saving and emission reduction of various strategies, as shown in Table 2. In order to reduce emissions, the installation of solar photovoltaic panels is the most effective emission reduction measure, with the energy saving rate and emission reduction rate as high as 19.8% and 38.8%, followed by solar collectors (9.7% and 19.5%), energy saving lamp replacement (5.3% and 14.4%) and shading reflectors (1.6% and 7%). Although the north wind deflector and local overhead strategy have little effect on carbon emission, they are of nice beneficial to the wind environment field in winter. Based on all the measures, the final energy saving rate of the reconstructed building is 63.8%, and the CO_2 emission reduction rate is 90.3%, with obvious performance improvement effect.

5. CONCLUSIONS

Taking a high-rise residential building in severe cold area as an example, the weak physical environment area is diagnosed. The green energy-saving measures are taken to renovate the buildings, he energy-saving and CO_2 emission reduction rate after renovation are predicted. From the results of building performance diagnosis, the wind speed at the corner of the building increased significantly, especially at the outdoor floor and top floor of the building, local wind speed up to 5.8 m/s. There is a glare problem next to the window, and the inside lighting is overly dim. The area of DA_{max} in all measuring points is as high as 51%. Operating energy consumption and carbon emissions are 85.26 kWh/m^2·a and 46.31 kg/m^3·a, respectively. From the aspects of form, structure, system and equipment strategy, the ecological energy-saving of the buildings are implemented. In terms of wind environment, the strong wind area in winter and quiet wind area in summer decreased significantly. About the light environment, indoor lighting is more uniform, the range of UDI100-2000 increased from 9.2% to 32.7%, UDI2000 which may cause glare decreased by 28.4%. In terms of thermal and energy consumption environment, the installation energy saving and emission reduction rates of solar photovoltaic panels are the highest, which are 19.8% and 38.8% respectively. By using DesignBuilder software to simulate the energy consumption of the target building, the final energy-saving rate of the reconstructed building is 63.8%, and the CO_2 emission reduction rate is 90.3%. Additional samples and cases are still required to be the complementation for the method profile proposed in the research. The study still offered a reusable and replicable evaluation system and retrofit methodology for optimizing the ecological environment of architectures under the cold condition.

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REFERENCES

[1] Santamouris, M. (2014). Cooling the cities – A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. Solar Energy, 103, 682–703.

[2] Pakalka, Saulius, Kęstutis Valančius, Kęstutis Čiuprinskas, Dominik Pum, and Markus Hinteregger. (2017). Analysis of possibilities to use phase change materials in heat exchangers-accumulators. Environmental Engineering International Conference ,10th.

[3] Kotchen, M.J. (2019) Longer-run evidence on whether building energy codes reduce residential energy consumption. Journal of the Association of Environmental and Resource Economists. 4(1), 135-153.

[4] Mauree, D., Coccolo, S., Kaempf, J., Scartezzini, J.L. (2017) Multi-scale modelling to evaluate building energy consumption at the neighbourhood scale. PLoS One. 12(9), 1834-1847.

[5] Yang, J., Fu, H., Qin, M.H. (2016) Evaluation of different thermal models in energyplus for calculating moisture effects on building energy consumption in different climate conditions. Building Simulation. 121(9), 15-25.

[6] Qu, S.L., Hu, W.C., Yuan, S.S., Yin, R.X., Ji, R. (2020) Optimal design and operation of thermally activated wall in the ultra-low energy buildings in China. Building Simulation. 13(4), 961-975.

[7] Chen, H., Wang, L.N., Chen, W.Y. (2019) Modeling on building sector & carbon mitigation in China to achieve the 1.5 ℃ climate target. Energy efficiency. 12(2), 483-496.

[8] Zhang, M.S., Ge, X., Zhao, Y., Xia, B.C. (2019) Creating statistics for building energy consumption using an adapted energy balance sheet. Energies. 12(22), 4293-4305.

[9] Huo, T.F., Ren, H., Zhang, X.L., Cai, W.G., Feng, W., Zhou, N., Wang, X. (2018) Energy consumption in the building sector: a statistical yearbook-energy balance sheet based splitting method. Journal of Cleaner Production. 185(6), 665-679.

[10] Peng, Z., Deng, W., Hong, Y.D. (2019) Materials consumption, indoor thermal comfort and associated energy flows of urban residential buildings: case studies from the cold climate zone of China. Structural Survey. 37(5), 579-596.

[11] Fanou, S.S. (2018) Cost efficient options and financing mechanisms for nearly zero energy renovation of existing building stock. Sustainability. 11(8), 2444-2456.

[12] Benslimane, N., Biara, R.W. (2019) The urban sustainable structure of the vernacular city and its modern renovation: a case study of the popular architecture in the Saharian region. Energy Procedia. 157(6), 1241-1252.

[13] Iuorio, O., Romano, E. (2017) Energy retrofit approach towards a multi-performance renovation of existing buildings. Sustainable Engineering and Design. 112(8), 322-332.

[14] Bi, F., Zhu, B.S. (2020) Research on key technologies of near-zero energy consumption transformation of green residential building envelope. Fresen. Environ. Bull. 29(12A), 11693-11701.

[15] Chen, N. (2021) Research on ecological building and sustainable building development. Fresen. Environ. Bull. 30(3), 2998-3004.

[16] Suman, N., Marinic, M., Kuhta, M. (2020) A methodological framework for sustainable office building renovation using green building rating systems and cost-benefit analysis. Sustainability. 12(6), 11-21.

[17] Kalamees, T., Kuusk, K., Arumgi, E. (2017) Cost-effective energy and indoor climate renovation of estonian residential buildings. Cost-Effective Energy Efficient Building Retrofitting. 36(5), 405-454.

[18] Assimakopoulos, M.N., Papadaki, D., Tariello, F., Vanoli, G.P. (2020) A holistic approach for energy renovation of the town hall building in a typical small city of southern Italy. Sustainability. 12(18), 21-36.

[19] Xu, W., Liu, C.P., Li, A.G., Li, J., Qiao, B. (2020) Feasibility and performance study on hybrid air source heat pump system for ultra-low energy building in severe cold region of China. Renewable Energy. 146(2), 2124-2133.

[20] Fu, S.L. (2021) Research on key technology of external energy-saving for low consumption and environmental protection building. Fresen. Environ. Bull. 30(6B), 7916-7922.

[21] Fang, L.W. (2021) Environmental impact assessment in the whole process of super high-rise building construction. Fresen. Environ. Bull. 30(6B), 7923-7932.

[22] Li, H.Y., Geng, G., Xue, Y.B. (2020) Atrium energy efficiency design based on dimensionless index parameters for office building in severe cold region of China. Building Simulation. 13(3), 515-525.

[23] Jiang, H.L. (2021) Analysis on the strong thermalinsulation performance of concrete sandwich straw compressed block for environmental protection requirements. Fresen. Environ. Bull. 30(8), 9803-9813.

[24] Jiang, H.L. (2022) Research on energy-saving effect of external thermalinsulation walls of residential prefabricated buildings in hot summer and cold winter areas. Fresen. Environ. Bull. 31(6), 5773-5782.

[25] Xu, X.D., Wu, Y.F., Wei, W., Hong, T.Z., Ning, X. (2019) Performance-driven optimization of urban open space configuration in the cold-winter and hot-summer region of China. Building Simulation. 12(3), 411-424.
[26] Chen, L.L., Song, G., Meadows, M.E., Zou, C.H. (2018) Spatio-temporal evolution of the early-warning status of cultivated land and its driving factors: a case study of Heilongjiang province, China. Land Use Policy. 72(3), 280-292.
[27] Xin, H., Tao, S., Meng, Y., Liu, L.Y., Cui, L.X., Liu, W.L., Sun, B.J., Liu, P., Zhao, W.G. (2020) Thermal biology of cold-climate distributed Heilongjiang grass lizard, Takydromus Amurensis. Asian Herpetological Research. 42(4), 114-123.
[28] Zhang, L.J., Wang, C.Z., Li, Y.S., Huang, Y.T., Pan, T. (2021) High-latitude snowfall as a sensitive indicator of climate warming: a case study of Heilongjiang province, China. Ecological Indicators. 122(3), 1072-1089.
[29] Tagliabue, L.C., Manfren, M., Ciribini, A., Angelis, E.D. (2016) Probabilistic behavioural modeling in building performance simulation-the brescia elux lab. Energy & Buildings. 128(9), 119-131.
[30] Bruno, S., Fino, M.D., Fatiguso, F. (2018) Historic building information modelling: performance assessment for diagnosis-aided information modelling and management. Automation in Construction. 16(7), 364-369.